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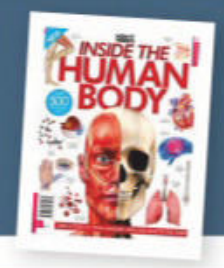

INSIDE THE HUMAN BODY

HOW IT WORKS

FEATURING LIVESCIENCE

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ISSUE 125

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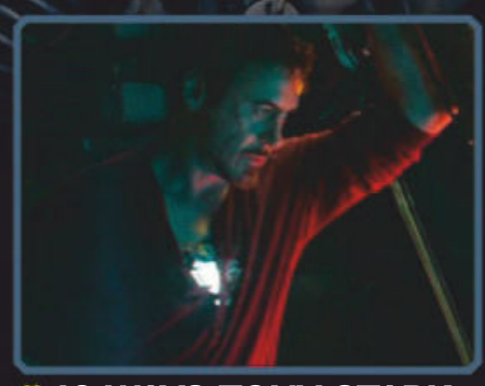
MINI-SUB EXPLORERS

How you can visit the deep ocean in an amazing hi-tech submersible

WHY SOME ANIMALS HAVE SUPERSENSES



10 WAYS TONY STARK COULD SURVIVE SPACE

CHERNOBYL: HOW DEADLY IS IT TODAY?

+ CYBORG INTERVIEW **HOW LIFE EVOLVES** WHAT'S BLOOD FOR? **NEW MOON MISSION**

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14+ AGE

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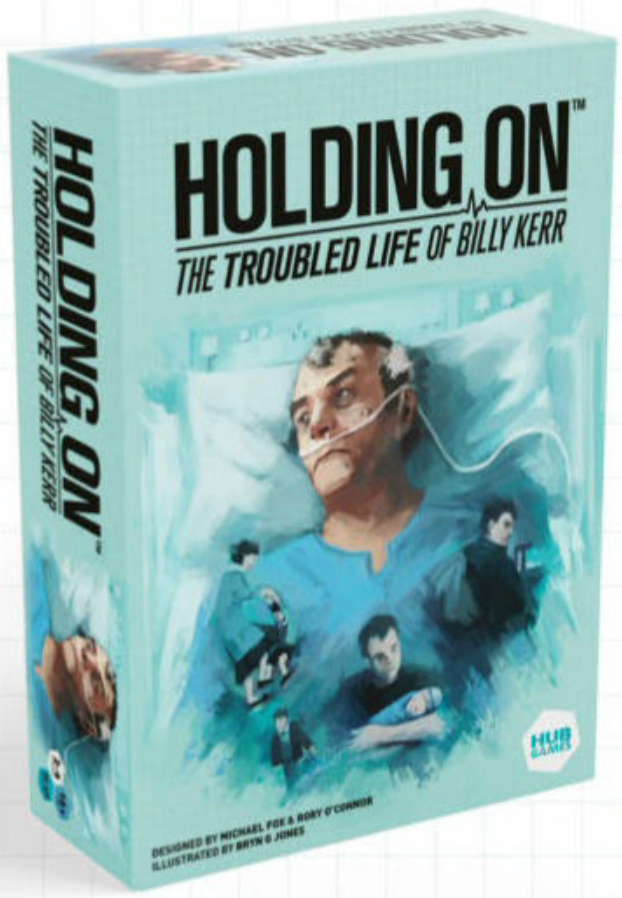

'All my life I've kept my mouth shut - out of loyalty, out of fear... out of shame.

And look where it's got me, lying here with my rear-end hanging out of a blue gown, all you lot fussing around me. Sure, that's no way to live. No way to die.'

Holding On: The Troubled Life of Billy Kerr is a co-operative game where players uncover the story of a dying man during his final days.

A truly emotionally impactful game, Holding On is a deep but accessible game that tells the extraordinary story of an ordinary life.

Find your nearest game store on www.findyourgamestore.co.uk

HUB GAMES

ISSUE **125**

WELCOME

The magazine that feeds minds!

"At nine gs you weigh nine times as much, everywhere is pressed down"

How to be a fighter pilot, page 20

Meet the team...

James
Production Editor
Isn't it everyone's dream to own their own submersible? The underwater explorers on page 28 are a fantastic way to view the deep.

Scott
Staff Writer
Imagine being able to see in 360 degrees like a chameleon! Discover more of the animal kingdoms super senses on page 42.

Baljeet
Research Editor
Did you know that blood accounts for seven per cent of your body weight. Find out more about what your blood does on page 36.

Duncan
Senior Art Editor
Modern medical science is incredible. Technology can now help the blind to see. Find out how tech can improve you on page 56.

We've got a double-special feature issue for you in this issue of **How It Works**. On page 20, we've visited the Royal Air Force's brand new High-G facility, where student pilots learn how to fly the latest fighter jets and cope with the enormous forces that press down on their bodies when manouevring at breakneck speeds. Then, on page 48 we ask how dangerous Chernobyl is today over 30 years after the nuclear reactor blew up. How has the radiation affected life in the exclusion zone?

On page 28 we go from sky high to miles deep in underwater explorers. Experience the world, but not as you know it, on page 42 as we discover animal super senses. We've spoken to a real-life cyborg about the microchips in his body on page 56, find out how China is ramping up a mission to the Moon, and more. Enjoy the issue!

Ben Biggs Editor

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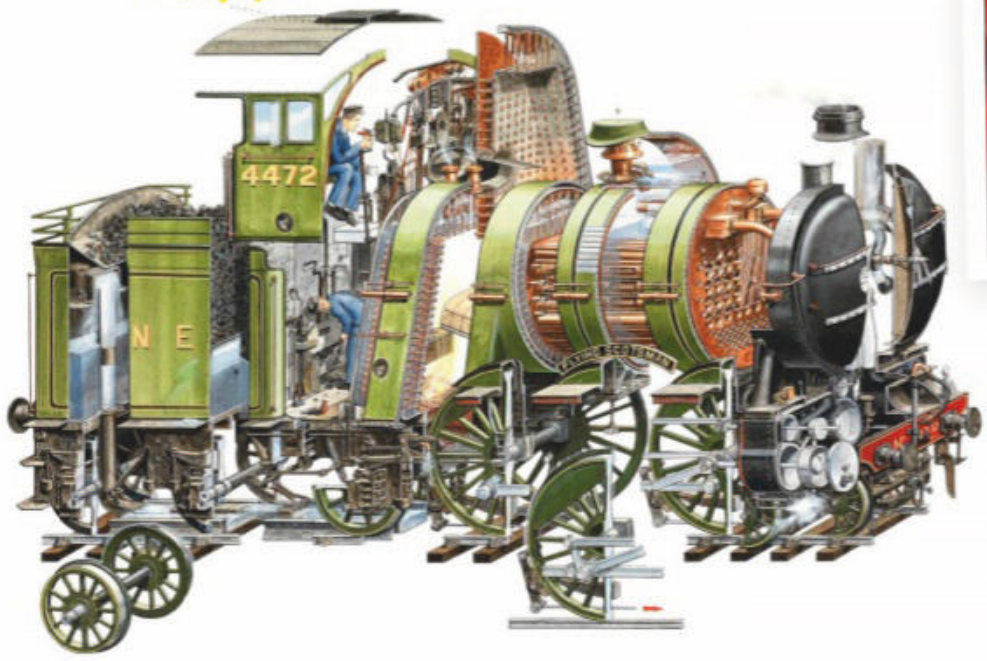


The Age of Steam 74

MEET THIS ISSUE'S EXPERTS...

James Horton
Former **HIW** member James is a biochemist and biotechnologist. He is currently doing a PhD in machine learning and evolutionary theory.

Jo Stass
Writer and editor Jo is particularly interested in the natural world and learning about the latest in technological innovations.

Jodie Tyley
The former Editor of **HIW** and **All About History** has tackled many topics in her career, from science fiction to science fact, and Henry VIII to honey badgers.

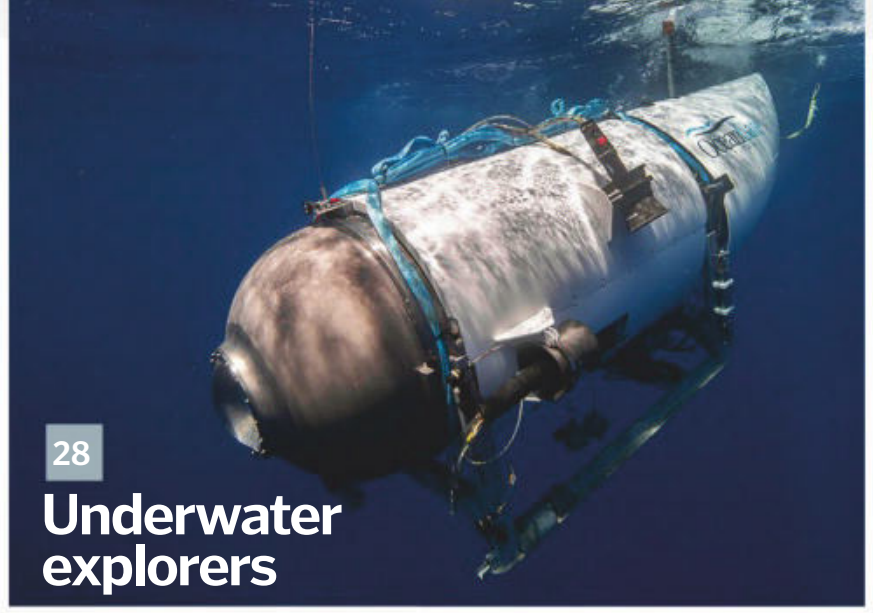
Charles Ginger
Charlie has a passion for history and a background in history writing, with a particular interest in the nineteenth century and Industrial era.

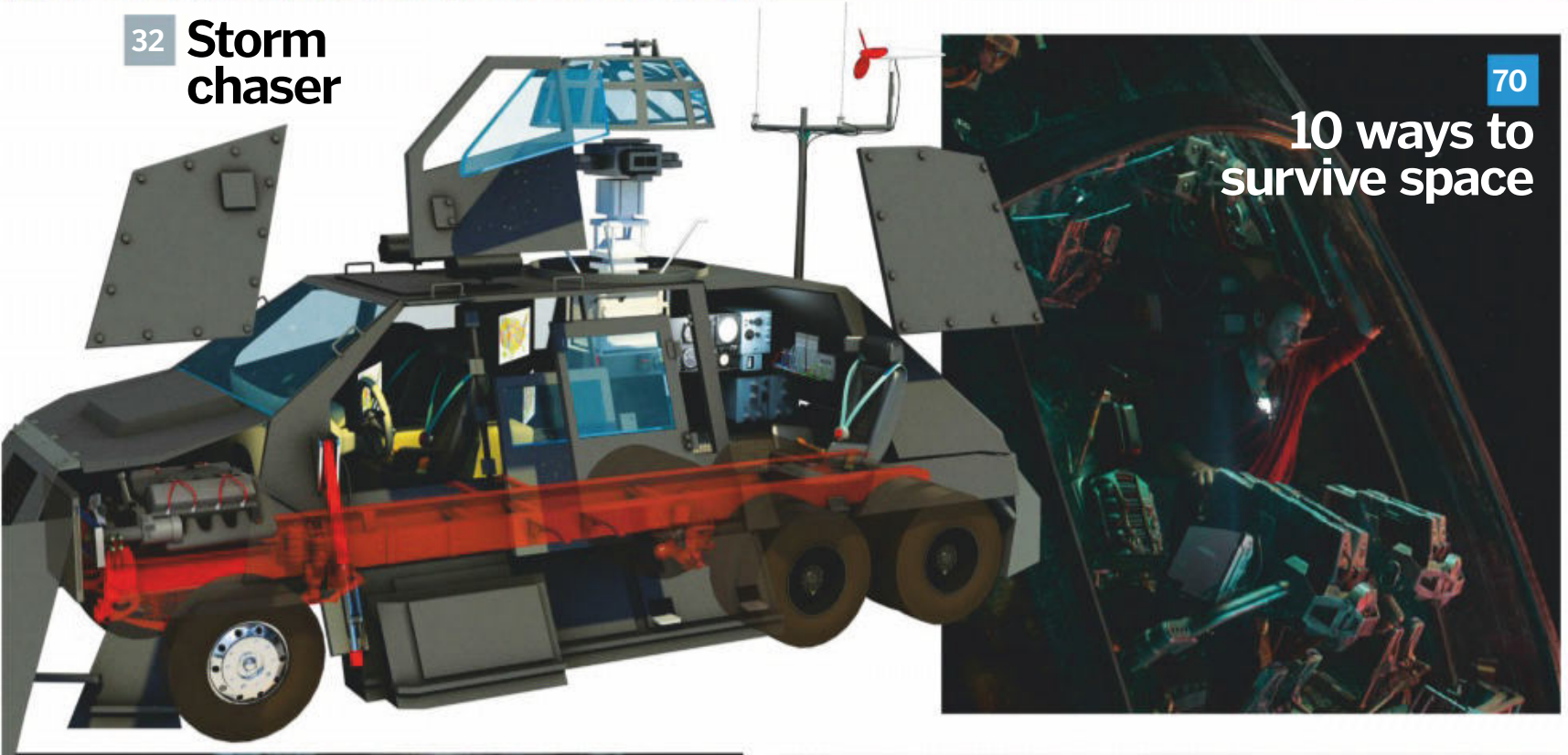
Laura Mears
Biomedical scientist Laura escaped the lab to write about science and is now working towards her PhD in computational evolution.

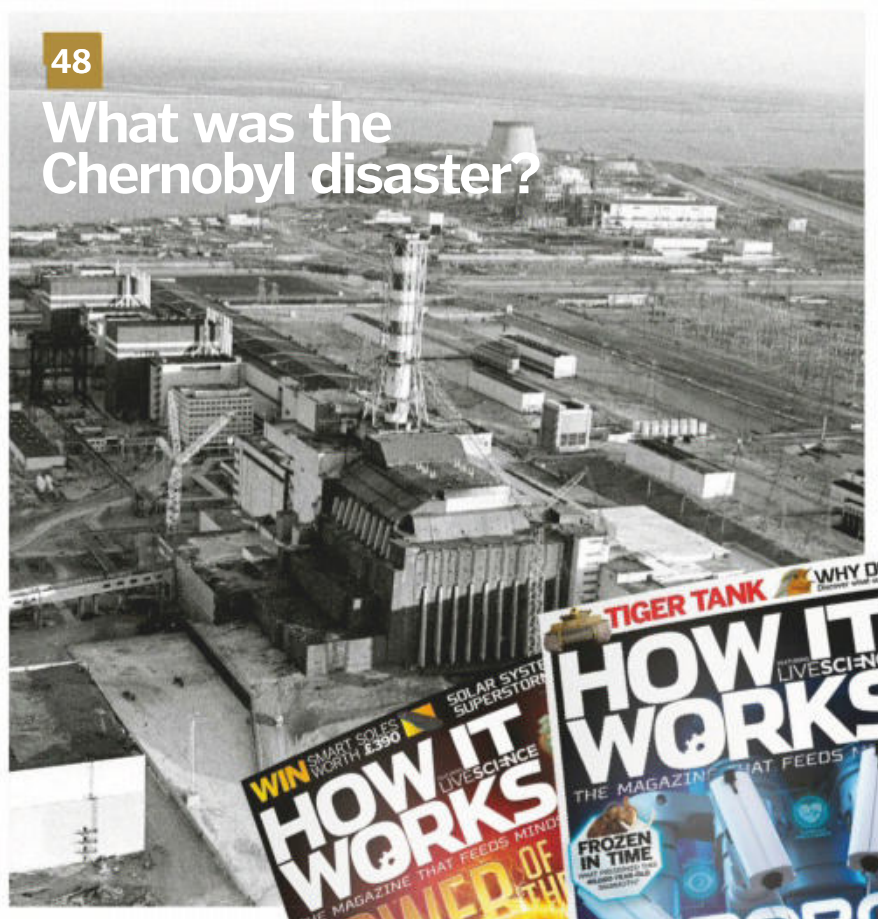
Stephen Ashby
Stephen is a writer and editor with video games and computer tech expertise. He is endlessly intrigued by Earth science.

Steve Wright
Steve has worked as an editor on many publications. He enjoys looking to the past, having also written for **All About History** and **History Of War**.

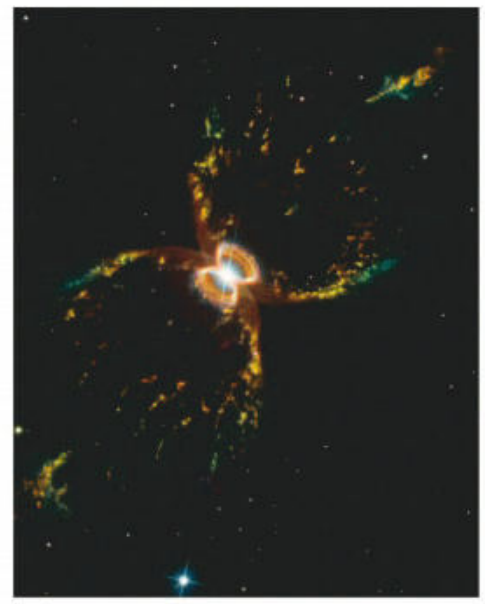
Katharine Marsh
Historian Kate is a former **History of Royals** writer and has a fascination with the scandals of kings and queens worldwide.







REGULARS



Tom Lean
Tom is a historian of science at the British Library working on oral history projects. His first book, *Electronic Dreams*, was published in 2016.

Victoria Williams
Evolutionary Biologist and science writer Vicky is fascinated by the natural world and is happiest when she's in the outdoors.

Mark Smith
Mark is a technology and multimedia specialist who has written for leading online and print publications for many years.

Amy Grisdale
Volunteer animal worker Amy has an enormous breadth of experience on animal and conservation projects. She specialises in environment topics.

World's largest aircraft takes flight

A double-bodied airplane with a wingspan as long as a football field took to the skies on 13 April, from the Mojave Air & Space Port in California. This was the first flight for Stratolaunch, billed as the world's largest aircraft. Designed by Stratolaunch Systems Corporation to carry satellites into low-Earth orbit, the craft spent 2.5 hours in the air above the Mojave Desert at altitudes of up to 5,180 metres. The aircraft is meant to carry satellites up to 10,970 metres, at which point it would become a mobile launch pad by releasing the satellites into orbit. Stratolaunch has a wingspan of 118 metres and is eight metres long, making it the world's largest plane by wingspan.

‘Aliens’ spotted above Norway

Even for Norwegians used to staring skywards at the Aurora Borealis, this must have been an unexpected sight. No wonder some thought they were having a close encounter with aliens. The colourful clouds high in the night sky were, in fact, caused by the vapours released by twin AZURE rockets shot from NASA’s Andøya Space Center on the Vesterålen archipelago in the north of the country. The rockets took measurements of the aurora and deployed gas tracers at 114 to 241 kilometres altitude.

GLOBAL EYE

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LIVESCIENCE

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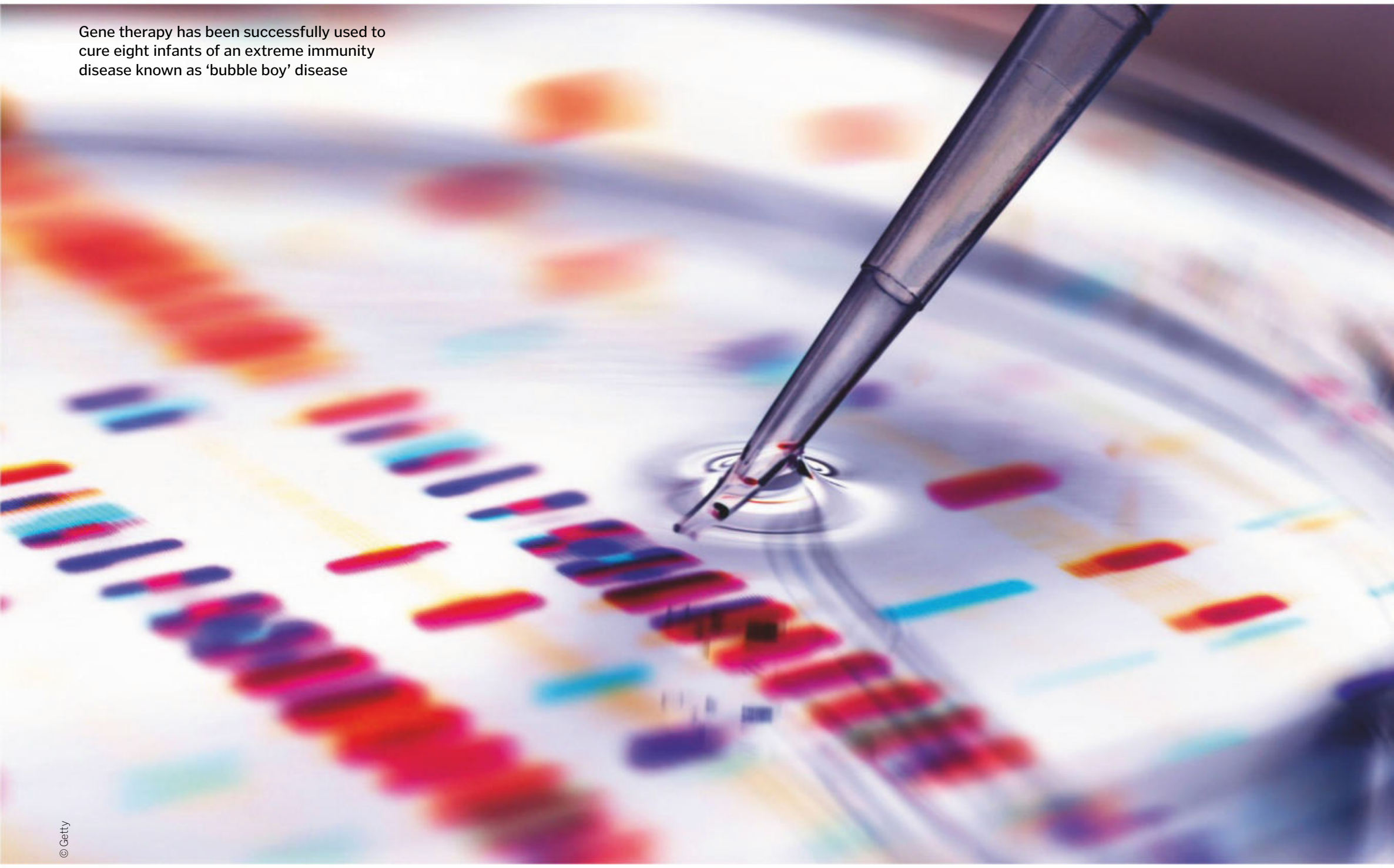


Gene therapy has been successfully used to cure eight infants of an extreme immunity disease known as 'bubble boy' disease

© Getty

HEALTH

'Bubble boy' disease cured by gene therapy

Words by **Rachael Rettner**

Eight infants with a severe immune disorder, sometimes known as 'bubble boy' disease, appear to be cured by experimental gene therapy, according to a new study published last month.

The disorder, called 'X-linked severe combined immunodeficiency' (SCID-X1), causes babies to be born with little to no immune protection, so they're prone to life-threatening infections. The new gene therapy involves using an altered version of HIV – the virus that attacks the immune system and causes AIDS – to deliver a correct copy of the gene causing the condition. Here, the virus was genetically engineered so it doesn't cause disease.

All of the children are now producing the immune cells needed to fend off the barrage of germs that humans encounter in their everyday lives, according to the study in *The New England Journal Of Medicine*. About 16 months after their treatment, the patients are developing normally and have not experienced serious side effects from the therapy. But the researchers said they will still need to be monitored for a longer period to determine if the treatment is long-lasting and doesn't cause side effects later in life.

The name 'bubble boy' disease comes from the highly publicised case of David Vetter, who was born in 1971 with SCID-X1, and spent most of his life in a plastic bubble while awaiting a bone-marrow transplant, according to CBS. He died at the age of 12 after receiving his transplant.

Some previous attempts to treat SCID-X1 with gene therapy have had serious side effects; one gene-therapy treatment in the 2000s resulted in several patients developing leukaemia. In the new study, the researchers first collected patients' bone marrow. Then they used the altered version of HIV to insert a working copy of the IL2RG gene into the bone marrow cells. These were then transferred back into the patients. Before this, the patients received a low dose of a chemotherapy drug to help make space in their marrow for the new cells to grow.

One concern with gene therapy is that after inserting a gene into people's DNA, genes that are next to the insertion site may turn cancerous, which has happened in previous cases where people developed leukaemia. But the new treatment worked to prevent this from happening by including 'insulator' genes that essentially block activation of the adjacent genes to prevent them from turning cancerous.

Five years of observations from NASA satellites reveal the steady disappearance of Peruvian forests

PLANET EARTH

NASA watches Peruvian forests disappear

Words by **Mindy Weisberger**

Years of deforestation in Peru are visible from space, tracked in a new animation created from NASA satellites Landsat 7 and Landsat 8 between 2013 and 2018, and the forest loss is escalating at an alarming rate.

Andrea Nicolau, a graduate research assistant at the University of Alabama, mapped forest loss in the images via a technique called spectral mixture analysis, which differentiates between types of land cover based on light properties in every pixel.

Nicolau determined that about 206 square kilometres of forest disappeared during the five-year period, the greatest loss taking place from 2017-18. The hardest-hit areas were found in buffer zones close to protected areas. Illegal gold mining is responsible for much of the deforestation on lands belonging to the indigenous Peruvian tribe known as Kotsimba Native Community. Indeed, NASA reported that those involved with mining operations and other activities threatening Peruvian forests have easier access to remote locations following the recent completion of Peru's Interoceanic Highway.

Madre de Dios rests near the Amazon basin, and is home to numerous rare species. But with deforestation rising, plants and animals that are endemic to the region face an uncertain future. By tracking and analysing patterns of forest loss, conservationists and government officials can strategise how to protect vulnerable species.

PLANET EARTH

Cancer cure for Tasmanian devils

Words by **Ben Biggs**

In recent years, the Tasmanian devil has faced a fresh new threat from a disease that causes deadly facial tumours among the species. DFTD (Devil Facial Tumour Disease) is spread from one devil to the next when they bite each other. The tumours can break facial bones and eventually kill the victim. However, during the last five years, the devils have evolved a resistance to the disease, with some individuals healing and recovering from DFTD without any human intervention. Tasmanian devils have the most powerful bite relative to its body size of any mammalian carnivore, and will frequently deploy it to establish a pecking order and in competition for food.

www.howitworksdaily.com

SPACE

Hubble's incredible happy birthday Crab photo

Words by **Brandon Specktor**

20 years ago, the Hubble Space Telescope revealed a giant crab in the sky. Just before its 29th birthday, the telescope once again trained its lenses on the Southern Crab Nebula to provide the world with a stunning reminder that, a) the cosmos is mysterious and beautiful, and, b) launching giant cameras into space is a really good idea.

Every year, Hubble spends a small portion of its time snapping a gorgeous anniversary picture like this one, according to a statement from the European Space Agency (ESA), the agency that manages the telescope in cooperation with NASA. The decision to image the Southern Crab Nebula for this year's birthday photo recalls the first encounter between the photographer and its subject in 1998, when Hubble imaged the complete hourglass structure of the nebula for the first time. The Southern Crab Nebula sits in the constellation Centaurus, about 7,000 light years away from Earth. What look like the legs and pincers of a cosmic crab are actually twin bubbles of gas and dust burped out by a pair of stars at the nebula's centre. This celestial Odd Couple is composed of one red giant – a huge, dying star in the process of moulting its outer shell of matter – and one white dwarf – the tiny, dead husk of hot crystal that remains once a red giant has released its last burst of gas.

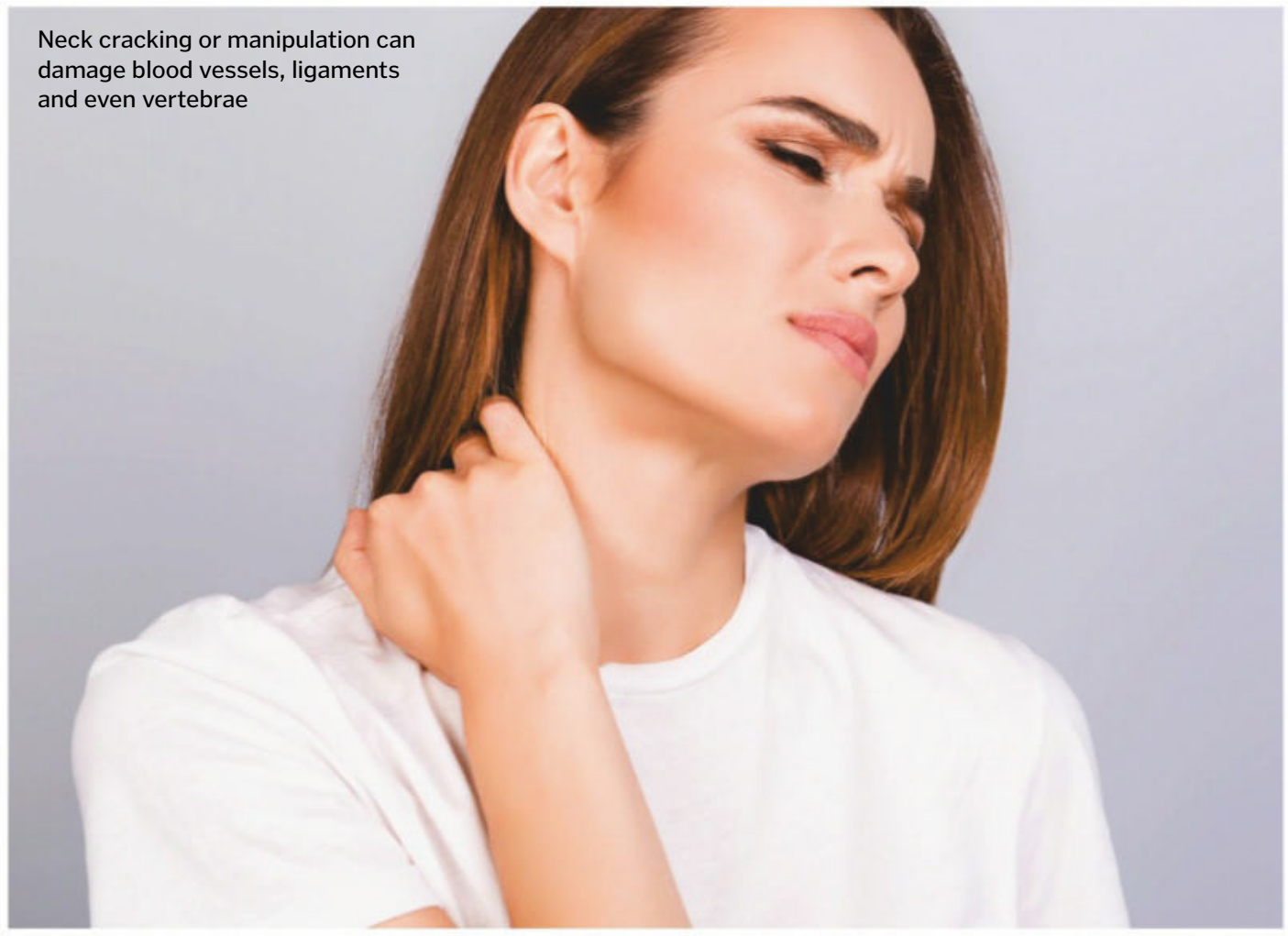
According to ESA, this binary duo coexists in a relationship where the dying red giant continuously feeds gas and dust into the white dwarf via its gravitational pull. After piling up for thousands of years, all that space schmutz may spark an eruption on the white dwarf's sizzling surface, sending matter scattering through space in giant bubbles. Astronomers think this has happened twice in the relatively recent past, giving rise to the twin splatters of glowing matter visible in Hubble's images of the nebula.

20 years after first exposing the Crab Nebula's wonky hourglass shape, the Hubble Space Telescope returns to capture this stunning anniversary image

HEALTH

Neck crack leaves woman partially paralysed

Words by **Mindy Weisberger**



Neck cracking or manipulation can damage blood vessels, ligaments and even vertebrae

© Getty

A young paramedic recently cracked her neck while stretching and ended up partially paralysed.

23-year-old Natalie Kunicki was watching a movie in bed after a night out drinking; she stretched her neck and heard a loud cracking sound. However, when she tried to get up about 15 minutes later, she couldn't move her left leg. She was rushed to University College London Hospital, UK, where doctors discovered that the neck crack had ruptured a vertebral artery – one of the major arteries in the neck. This created a blood clot that triggered a stroke, causing paralysis on her left side, according to *Unilad*.

In general, neck cracking and aggressive manipulation of the neck vertebrae should be avoided because they can cause ruptures in the walls of critical blood vessels that supply blood to the brain, Dr Robert Glatter, an emergency physician at Lenox Hill Hospital in New York City, told **Live Science**, "A tear in the wall of the blood vessel can lead to a stroke if a blood clot forms at the site of the injury, and later breaks free to block blood flow to the brain."

Kunicki's surgeons were able to repair her damaged artery, though they were unable to remove the blood clot. While it is expected to dissolve over time without causing further damage, Kunicki's paralysis persisted in the weeks after the surgery, *The Sun* reported. Kunicki has regained some movement, though she still faces months of rehabilitation.

One of 26 human skeletons recently revealed during digging for a water-pipeline project in Oxfordshire

© Thames Water

HISTORY

Pipeline engineers find 'Ritually buried' skeletons

Words by **Brandon Specktor**

A pipe-laying project in Oxfordshire carried out by British utility company Thames Water has led to the discovery of 26 human skeletons, some believed to be nearly 3,000 years old.

The oldest skeletons are thought to date to the Iron Age (which lasted from the 8th century BCE to the 2nd century CE), experts from the local Cotswold Archaeology heritage society said, providing fresh insights into how local communities lived before the Roman conquest of Britain began in the first century. Some of the skeletons were buried in what appeared to be a ritual manner, as they show similarities to nearby Iron Age pit burials that "might have involved human sacrifice," Cotswold Archaeology chief executive Neil Holbrook said in a statement.

Among the skeletons in the new find, the diggers also uncovered a trove of artefacts, including fragments of dwellings, pottery, cutting tools, animal carcasses and a decorative comb. The skeletons and objects have been removed for forensic analysis so that the pipeline project may continue.

IN ASSOCIATION WITH LIVESCIENCE

Researchers swabbed dog's shoulder blades and the men's beards to collect bacteria samples

© Getty

HEALTH

Beards host more harmful bacteria than fur

Words by **Brandon Specktor**

A small European study has found that the average man's beard is more replete with human-pathogenic bacteria than the dirtiest part of a dog's fur.

Researchers analysed skin and saliva samples from 18 bearded men (whose ages ranged from 18 to 76), and fur and saliva samples from 30 dogs (whose breeds ranged from schnauzer to German shepherd), at several European hospitals. The researchers were looking for colonies of human-pathogenic bacteria in both man and dog – not in an attempt to beard-shame the hirsute masses, but rather to test whether it was safe for humans to use the same MRI scanners that dogs had previously used. In fact, it was the humans who were the dirtier patients. Not only did the men's beards contain significantly more potentially-infectious microbes than the dogs' fur, but the men also left the scanners more contaminated than the animals.

"As the MRI scanner used for both dogs and humans was routinely cleaned after animal scanning, there was substantially lower bacterial load compared with scanners used exclusively for humans," the researchers wrote in the study. The tests showed that all 18 men showed "high microbial counts" on their skin and in their saliva, while only 23 of the 30 dogs did. Seven of the men and four of the dogs tested positive for human-pathogenic microbes – the kind of bacteria that can make a person ill if they colonise the wrong part of the host's body. These microbes included *Enterococcus faecalis*, a common gut bacteria that is known to cause infections (especially urinary tract infections) in humans, and several cases of *Staphylococcus aureus*, a skin/mucous-colonising bacteria that may live on up to 50 per cent of all adults, but can cause serious infections if it enters the bloodstream.

Despite the comparatively higher microbial counts in this small sample of bearded men, the takeaway from this study isn't, "reach for that electric razor *now*, Rasputin!"; as the authors wrote, "there is no reason to believe that women may harbour less bacteriological load than bearded men." Instead, it's that humans leave more potentially infectious bacteria behind in hospitals than you'd like to imagine, and simply sanitising a surface is apparently not enough to solve the problem.

A new airplane wing design assembles like a jigsaw puzzle and changes shape in response to stress

TECH

Jigsaw airplane wing adjusts mid-flight

Words by **Stephanie Pappas**

A new type of airplane wing assembled like a jigsaw puzzle could make for lighter, more efficient aircraft.

NASA and Massachusetts Institute of Technology researchers tested the wing design in a NASA wind tunnel, where the technology performed better than expected, said Benjamin Jenett, one of the wing's developers and a graduate student at MIT. The new wing is light and flexible, able to adjust its shape mid flight depending on the needs of the pilot. "You can make any geometry you want," Jenett said.

Conventional airplane wings are made of metal and composite materials, so they're fairly heavy. They also involve moving parts, like the flaps and ailerons you might watch tilting up and down if you get an overwing seat on a cross-country flight. The new wing is made of thousands of little triangular struts, each made of matchstick-sized polymer pieces. The team manufactured the struts from a polyethylene resin injected into a mold.

The lattice of struts was then assembled into a five-metre wing, about as big as a wing on a single-seater airplane. The lattice-like wing is covered with a thin sheet of polymer and has a density of just 5.6 kilograms per cubic metre.

But lightness isn't the only advantage of the new wing design. It's also flexible. By strategically placing stiff and flexible components in the lattice pattern, the researchers can build a wing that changes shape in response to the stresses around it. Instead of having to lift a flap or move an aileron, a pilot could simply manoeuvre the plane, and the wing would change shape automatically.

Poppies and other wildflowers bloom in Southern California's Antelope Valley

PLANET EARTH

New 'superbloom' snapped by NASA

Words by **Stephanie Pappas**

California's 'superbloom' appears in almost unbelievable colour in a new aerial image from NASA. The shot comes courtesy of NASA Armstrong Flight Research Center aerial photographer Jim Ross, who snapped it from a T-34 airplane on 2 April.

The image shows Southern California's Antelope Valley carpeted in wildflowers. The spray of colour is an annual event, made more intense by this year's wet winter in California. When the flowers are as dramatic as this year's display, they're called a 'superbloom'.

The last season that resulted in a superbloom in California was in 2017. The desert environment of Southern California might seem a strange spot for wildflowers, but the orange California poppy (*Eschscholzia californica*) is suited to hot environments. According to the US Forest Service, the plants bloom in the spring, then go dormant in summer, allowing their tops to die off and surviving underground as a taproot.

PLANET EARTH

European glaciers could vanish by 2100

Words by **Megan Gannon**

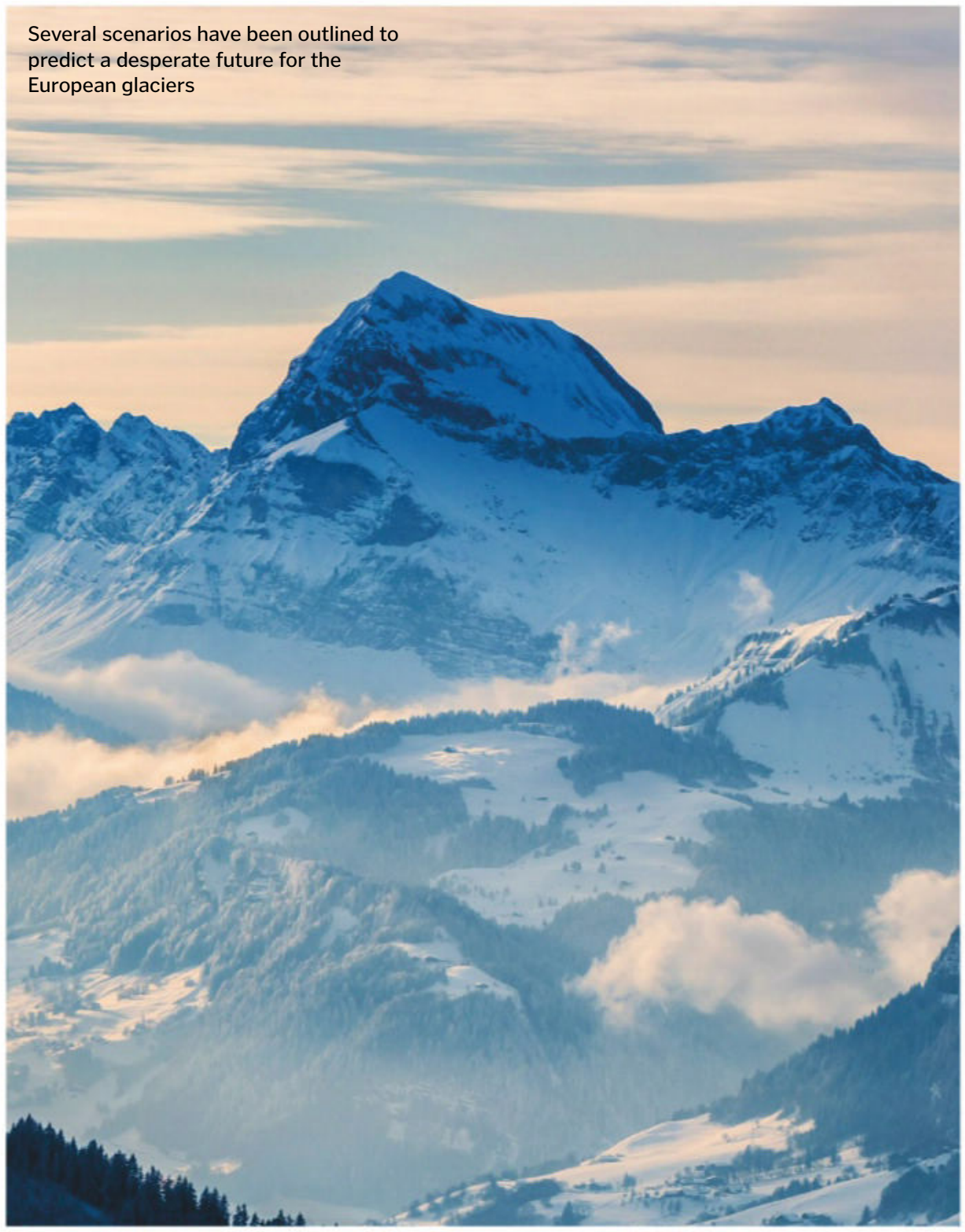
The glaciers that cover the European Alps could disappear by 2100 if human-caused global warming greatly increases over the next several decades, according to new climate models.

"In a bad case, everything will almost be gone," Harry Zekollari, a climate scientist with the Swiss Federal Institute of Technology in Zurich. Even if humans manage to prevent further global warming, the glaciers will still lose half their volume by 2050, Zekollari and his colleagues found.

The researchers simulated the evolution of nearly 4,000 individual glaciers in the European Alps with a new computer model. Scientists used 2017 as their baseline year, with the glaciers starting out at a volume of about 100 cubic kilometres, or the equivalent of 40 million Olympic-size swimming pools.

The researchers found that about 95 per cent of the ice would disappear under the most pessimistic warming scenario, RCP8.5, which projects that the global temperature average could rise by up to 4.8 degrees Celsius by 2100. Even under a more-intermediate warming scenario – RCP4.5 – 80 per cent of the glacier volume would vanish.

Under a more limited emissions scenario known as RCP2.6 (a rise of less than two degrees Celsuis), about one third of the present-day glacier volume would remain in 2100. Whichever global warming scenario plays out, the glaciers will shrink by half by 2050, because glaciers have a slow response time.



Several scenarios have been outlined to predict a desperate future for the European glaciers

© Getty

© Getty

The world's last known female Yangtze giant softshell turtle (seen in 2015) died at Suzhou Zoo on 13 April

ANIMALS

Extinction inevitable for giant turtle species

Words by **Brandon Specktor**

The Yangtze giant softshell turtle (*Rafetus swinhoei*) is considered the most critically endangered turtle in the world, with only four known individuals left on Earth.

On 13 April, that population fell to three, as the species' last known female died in a zoo in Suzhou, China, according to the BBC. The captive turtle was more than 90 years old, and died shortly after an attempt to artificially inseminate her. No complications from the insemination procedure (which was the turtle's fifth) were reported, and the cause of death is being investigated.

The rare turtle is survived by one male, who also lives in the Suzhou Zoo and is believed to be about 100 years old. Scientists had been trying to breed the pair for years, a 2018 *New Yorker* article reported, but were unsuccessful due, in part, to the male's damaged penis.

The world's final two known *R. swinhoei* turtles live in separate ponds in Vietnam. Their genders are unknown. The species used to be widespread in the fresh waters of China and Vietnam, according to the *New Yorker*, but have dwindled to near-extinction due to hunting and habitat loss.

An artist's impression shows a black hole's accretion disc, with gas and dust from nearby nebula being pulled toward the disc

SPACE

Black hole's 'diet' reveals growth

Words by **Rafi Letzter**

You've seen the first close-up of a black hole. Now, get ready for the faint wisps of matter surrounding it.

The international team responsible for the first ever image of a black hole's shadow already has plans to take a better, more detailed image. And that image could reveal new details about the matter and magnetic fields wrapped around the supermassive, distant object at the centre of galaxy Messier 87 (M87).

More detailed images, along with movies of the black hole that are already in the works, could help explain how black holes gobble up matter from the rings of hot gas swirling around them (called accretion discs) and how the objects produce bright jets of superfast matter on the scale of galaxies. That's according to researchers from the Event Horizon Telescope (EHT) team who spoke to physicists at the American Physical Society's April meeting.

To image the M87 black hole in more detail, the researchers need to alter their approach, said Shep Doeleman, the Harvard University astronomer who lead the EHT team. Specifically, the scientists need to increase the frequency of the radio waves they're studying and add new radio telescopes to the EHT network. Both projects are already underway, he said, and should sharpen the already remarkably sharp image.

In particular, the team hopes to image curling wisps of duller matter that simulations suggest should surround that bright ring already pictured, said Avery Broderick, an astrophysicist at the University of Waterloo in Canada who works on interpreting data from the EHT. The shapes of those wisps should tell physicists whether a long-held theory of how matter gets knocked from a black hole's accretion disc into its throat is correct.

Physicists believe, Broderick explained to Live Science, that as turbulence shakes the hot material of the accretion disc, its shaking particles magnetically tug on each other across vast distances. This tugging causes some of the whirling matter to slow down and fall out of orbit past the event horizon and into the black hole; this material forms the wisps that the researchers hope to study.

"What those wisps would do is give you a way to directly test that, because you're looking at [the direct result of magnetic turbulence]," Broderick said. Careful imaging of the wisps, combined with an effort to image the black hole in motion, would help physicists understand in unprecedented detail how black holes eat and grow.

WISH LIST

The latest **SUMMER** tech

© Coo est

Coolest Cooler

Price: **From $249.99 / approx. £190**
www.coolest.com

This appropriately-named 57-litre box is the Swiss army knife of coolers. Much more than a standard portable food and beverage container, it can be customised with a battery-powered blender, LED lid light, solar panel charger and more. Durable and mobile thanks to its rear rubber wheels and telescopic handle, it's a great addition to any beach party.

Spectacles 2 (Nico/Veronica)

Price: **£199.99 / $199.99**
www.snapchat.com

Sunglasses are a must while enjoying the summer Sun. However, with Spectacles 2 by Snapchat, wearers are able to not only protect their eyes but safely record their fun in the Sun. With the ability to record PoV videos at 1216 x 1216 pixels at 60 frames per second, Spectacles 2 can capture bursts of footage at the touch of a button. Captured video footage, photos and audio is not only compatible with the Snapchat app but can also be exported to other platforms in different formats.

© Snapchat

© Sunscreenr

Sunscreenr UV camera

Price: **$79 / approx. £60**
www.sunscreenr.com

Skin care and protection are incredibly important during the year's hotter months. However, pale or translucent sunblocks can be tricky to see when applied, often leading to areas being missed resulting in a nasty burn. The Sunscreenr UV camera has been developed to detect these missed patches and show you how protected you really are. By filtering out UV light, this compact gadget is able to see your sunblock coverage or lack thereof with the accompanying app, allowing you to stay on top of your UV protection.

Kingii wearable

Price: **$89.99 / approx. £70**
www.kingii.com

Stay safe while surfing the waves with the Kingii inflatable wristband. This compact safety accessory houses a small replaceable carbon dioxide cartridge which will, at a flip of a switch, inflate a small bright orange bag. The bag will bring anyone struggling underwater back to the surface and it is small enough to grip onto until you are able to get back to shore.

© Kingii

Turtle Shell 3.0

Price: **£79.99 / $99.95**
www.outdoortechnology.com

What's a pool party without music? Most portable speakers run the risk of water damage when sitting poolside. Getting wet, however, isn't a problem for the Turtle Shell 3.0. In fact, it's built to join you in the pool. As a floating wireless speaker, the Turtle Shell is durable and waterproof, provides 20 hours of playtime and will remain Bluetooth connected up to around ten metres.

© Outdoor Tech

© VARTA

Slim Power Bank 6000

Price: **£26.99 / approx. $35**
www.varta-consumer.com

Keep connected while you enjoy the outdoors this summertime with the Slim Power Bank 6000 from VARTA. With the ability to charge two devices at the same time, the dual output can fully charge either two and a half phones or one tablet. This ultra slim, compact power bank is only 1.2 centimetres thick, while still housing a 6000 mAh Li-polymer battery.

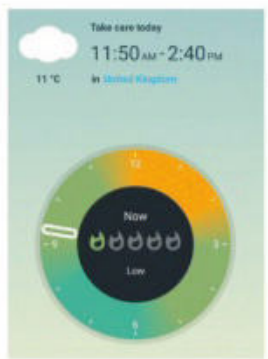
© Outdoor Tech

APPS & GAMES

UVLens

Developer: **Spark 64**
Price: **Free / Google Play / App Store**

Keeping a close eye on your skin's exposure to UV radiation has now been made simpler with the UVLens app. Monitor daily changes in UV and receive reminders to protect yourself.



PackPoint Travel Packing List

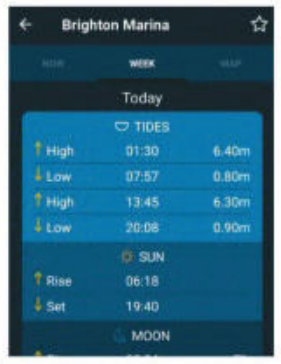
Developer: **Wawwo**
Price: **Free / Google Play / App Store**

Organise your packing with this travel organiser, jam-packed with tips and lists to ensure you don't leave anything important behind, and you can even share your lists with family and friends.

Tides Near Me

Developer: **Shelter Island Mapping Company, LLC**
Price: **Free / Google Play / App Store**

Make the most of your beach holidays with this tidal prediction app. Monitor the best time to take a dip in the ocean and discover when the Sun and Moon will rise or set at your destinations.



Drink Water Reminder

Developer: **Simple Health Lab**
Price: **Free / Google Play**

During hot summers, it can be easy to forget to take a sip of water. However, with this water tracker and reminder app, users can keep an eye on their water intake and receive alerts when it's time to hydrate.

HOW TO BE A FIGHTER PILOT

How It Works visits the RAF's High-G facility to see how fighter pilots prepare for their greatest battle – against the forces of physics itself Words by **Scott Dutfield**

Royal Air Force pilots go through rigorous training to get their wings. Despite years of technical training for combat, one of the biggest hurdles to overcome as a fighter pilot are the forces of the Earth, in the form of gravity. **HIW** travelled to RAF Cranwell, Lincolnshire, to see first hand how a human centrifuge can prepare pilots for future military missions.

WHAT IS G-FORCE?

As we're all aware, gravity is the force keeping our feet firmly on the ground. Every particle of matter on Earth is subjected to its planetary pull. At sea level you will experience the force of gravity at one g, which is 9.8 metres per second squared and is equivalent to your body weight. As an object accelerates or decelerates it will

DID YOU KNOW? *NATO requires a training centrifuge to reach three gs in one second*

experience different levels of g-force, categorised as either positive or negative force. The faster the rate of acceleration, the more gs or positive g-force is applied. Similarly, as a jet turns in flight, the acceleration increases dramatically and so greater amount of gs are experienced by the pilot. For example, if a pilot experiences three gs of positive force, that would equate to three times their body weight pushing down on their body during flight. The same is true for deceleration: the quicker the rate an object slows down the more negative g-force it will experience. For fighter jet pilots, this occurs during roll-outs or bunts (a spin and a half-loop). It's these gravitational obstacles that have forced the invention of sophisticated training machinery, such as the human centrifuge, to put pilots through their paces in preparation for the real thing.

OUT WITH THE OLD, IN WITH THE NEW

This year saw the closure of the UK's long-standing centrifuge facility at Farnborough, Hampshire. Here, the centrifuge had been giving pilots a gravitational glimpse into their flying future since 1955. However, as time has passed, the Farnborough centrifuge has reached its retirement and no longer meets the standards of the North Atlantic Treaty Organization (NATO). A new £44 million (approximately $57 million) training facility and human centrifuge at RAF Cranwell, Lincolnshire, is giving pilots the opportunity to experience flight simulation like never before.

Traditionally when using a human centrifuge to train pilots for high g-force exposure, trainees are strapped to a stationary gondola and sent spinning to reach levels of g-force comparable to those experienced during fighter jet flights. However, at Cranwell's new facility the 39-ton centrifuge places a pilot into a virtual cockpit, where spinning sessions are carried out in a gondola that turns 180 degrees. The immersive experience is heightened by a digital simulation screen in place of a real glass window, delivering a digital flight programme similar to a flight simulator. As the motor-driven arm grasps the high-tech gondola, rapid acceleration replicates changes in g level. Rather than these levels being dictated completely by a control room, pilots strapped into Cranwell's centrifuge are able to use one of three interchangeable fighter jet cockpits to steer and alter g levels while spinning. Pilots need to withstand a session in the centrifuge at nine gs for 15 seconds in order to progress to the real thing. This feat is gradually achieved over a period of a couple of days for experienced pilots seeking to transfer to faster fighter jets, such as a Tornado or a Typhoon. A centrifuge doesn't only test the physical capabilities of future pilots, but also future equipment that will be placed in a jet cockpit. This allows engineers to evaluate how effective a radio, for example, will be under nine gs.

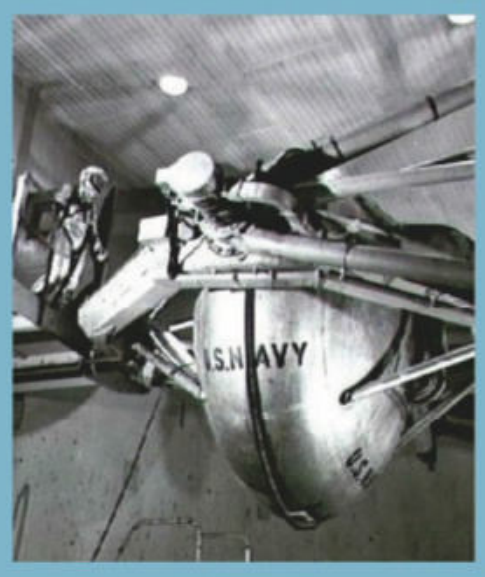
FEELING THE FORCE

Accelerating in gravity doesn't come without its physical downfalls. Changes in g-force affects not only the pressure applied to the external body but also its internal workings. Without mechanical intervention, the blood in the body is pulled down towards the Earth, pooling in the pilot's feet. This sudden relocation of blood results in the depletion of oxygen in the brain, which can render a pilot unconscious. Commonly known as 'grey out', G-LOC (gravity induced loss of consciousness) is a pilot's main concern when carrying out turns

"Pilots need to withstand a session in the centrifuge at nine gs for 15 seconds"

The first centrifuge

Modern-day human centrifuges serve a very different purpose to their predecessors. First used in medicine in the early 1800s, a patient would be placed on an extended spinning arm as a 'treatment' for nervous disorders, which was originally controlled via a rope and pulley system. Over time the human centrifuge has received a mechanical makeover, with one of the first modern-day examples constructed by American engineers Harry G. Armstrong and J.W. Heim in 1935. Construction of one of the world's largest human centrifuges was completed in 1949. It weighed 180 tons, and had a 15-metre-long arm. Previous examples had only spanned a few metres. The spinning behemoth, constructed in Johnsville, Pennsylvania, could reach 40 gs and was used to train astronauts for the Mercury, Gemini and Apollo programs.



The giant centrifuge was also used to train early Space Shuttle astronauts

Effects of g-force

What did we experience under the extreme changes in gravity in the centrifuge?

G-LOC
Positive g-force

Redout
Negative g-force

Stretched face
Under immense positive g-force, the skin on our face began to drag down following the direction of gravitational pull.

Head
Filled with blood, our face became red and bulging causing lack of concentration.

Red eyes
Our vision becoma blurry as the blood reached the head, causing bloodshot eyes. In more extreme negative g-force, veins can rupture.

Neck and back
Our spine bore most of the pressure of positive g-force, and was where most of the gs could be felt.

Pooling blood
Blood migrated to the lowest possible place in the human body: our feet.

Weak legs
As the rate of deceleration increases blood moved quickly to the head, causing reduced function in our lower limbs.

DID YOU KNOW? *The F-35 Lightning II holds the record for the most powerful engine on a fighter jet, rated at 28,800lb of thrust*

We entered the gondola at the base via folding stairs that lead to the cockpit

We were able to communicate with control via microphones placed in our helmet during the session

The gondola's cockpit is interchangeable between replicas of the Hawk, Typhoon and F-35 Lightning II

Within the gondola, we viewed a simulation screen showing a virtual window of a fighter jet

We wore an anti-g suits to help prevent blood from pooling in our feet

During a training session the centrifuge will spin 34 times per minute

Turbine
Similar to those used in wind energy, this turbine uses the power produced by the motor to spin the centrifuge arm and gondola.

Counterweight
Balance is critical during a centrifuge run, therefore an 11-ton counterweight is used to offset the weight of the gondola, keeping the centrifuge balanced.

3
The number of interchangeable aircraft cockpits

34
The number of rotations per minute

1 second
Time taken to accelerate from one to nine gs

20 tons
Weight of the centrifuge gearbox and main drive

Powerful motor
The main drive and gearbox below ground can generate around 3,200 kilowatts at peak power output.

Vital connection
Electrical power, signals, gas and hydraulics are fed along the centrifuge's arm in to the gondola.

HI-G machine

We took a a spin on the RAF's brand new training centrifuge

Steel arm
The 7.5-metre-long aluminium/steel arm holds the gondola in place. The length of the arm can affect the amount of gs it can generate.

Rotating gondola
This is where we sat for our run. The gondola can also rotate 180 degrees on a vertical axis.

Three cockpits
The gondola contains three interchangeable cockpits, in order to replicate three RAF fighter jets: the Hawk, Typhoon and F-35 Lightning II.

Preprogrammed simulation
The cockpit's widescreen display provided us with a realistic visual experience of flying a fighter jet.

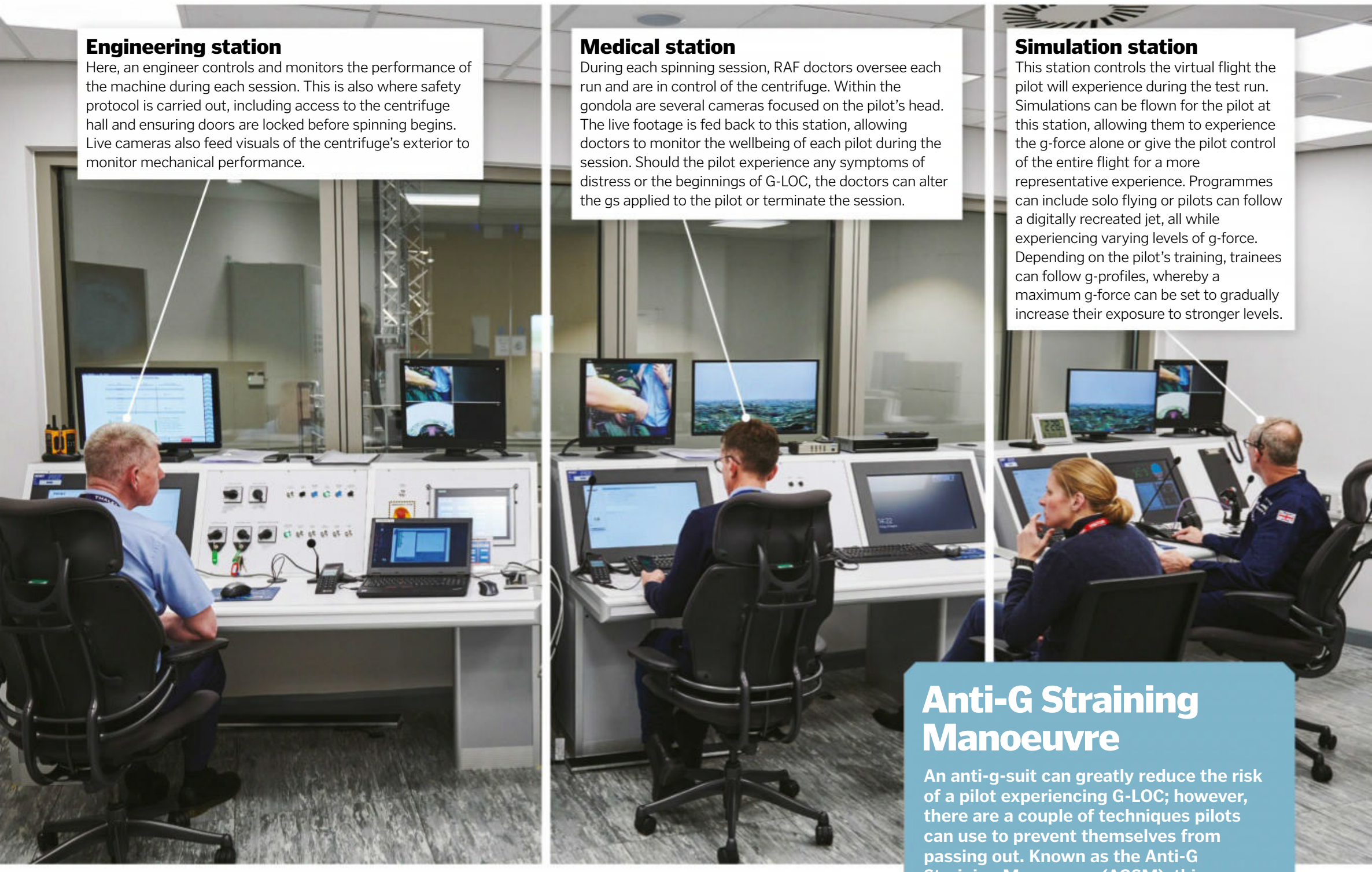
G-sensors
Placed in the pilot's seat, several sensors monitor the g-force within the cockpit during runs.

25 years
The intended lifespan of the centrifuge

4,000+
The horsepower delivered by the main drive and gearbox

Taking control

Three separate stations control each centrifuge session and virtual experience, ensuring the pilot's safety



Engineering station

Here, an engineer controls and monitors the performance of the machine during each session. This is also where safety protocol is carried out, including access to the centrifuge hall and ensuring doors are locked before spinning begins. Live cameras also feed visuals of the centrifuge's exterior to monitor mechanical performance.

Medical station

During each spinning session, RAF doctors oversee each run and are in control of the centrifuge. Within the gondola are several cameras focused on the pilot's head. The live footage is fed back to this station, allowing doctors to monitor the wellbeing of each pilot during the session. Should the pilot experience any symptoms of distress or the beginnings of G-LOC, the doctors can alter the gs applied to the pilot or terminate the session.

Simulation station

This station controls the virtual flight the pilot will experience during the test run. Simulations can be flown for the pilot at this station, allowing them to experience the g-force alone or give the pilot control of the entire flight for a more representative experience. Programmes can include solo flying or pilots can follow a digitally recreated jet, all while experiencing varying levels of g-force. Depending on the pilot's training, trainees can follow g-profiles, whereby a maximum g-force can be set to gradually increase their exposure to stronger levels.

and rolls in the air, which can lead to potentially fatal accidents. The reverse, however, can occur when free falling and experiencing negative g-force, whereby blood rushes to the head causing 'redout'. This is where the training on the human centrifuge comes in very useful. By exposing trainee pilots to varying levels of g-force, they can gain the skills and experience needed to combat the effect of G-LOC in the sky, while in a safe and controlled environment. During a test run on the centrifuge, should a trainee experience G-LOC or need medical assistance, the control room is able to execute an emergency stop, quickly reducing the centrifuge's speed down to a single g. The centrifuge is programmed to place the gondola precisely outside the medical room door for fast extraction. Although there are no long-lasting health effects on trainee pilots, experiencing high levels of g-force can cause small bruises called petechiae. This is where capillaries along areas of the body, particularly the arms, rupture under the huge force, also known as 'geasles'.

"There are several ways in which pilots can combat the occurrence of G-LOC"

There are several ways in which pilots can combat the occurrence of G-LOC, including breathing and straining techniques. However, in order to safely reach the g demands of fighter jets, pilots are equipped with a flight suit which acts as a full body blood pressure cuff. These anti-g suits can afford pilots an extra few gs of protection during both a simulation and a real flight. A network of pipes fills each khaki-coloured suit, which is divided into a jacket, trousers and socks. During test runs, these pipes are connected via a single outlet to a gas supply feed into the gondola. As the pilot experiences increased gs, the suit will inflate to compress the body and prevent excessive blood pooling.

Anti-G Straining Manoeuvre

An anti-g-suit can greatly reduce the risk of a pilot experiencing G-LOC; however, there are a couple of techniques pilots can use to prevent themselves from passing out. Known as the Anti-G Straining Manoeuvre (AGSM), this method of G-LOC prevention involves pilots continuously clenching all skeletal muscles, such as the legs, arms and abdomen. In doing so, this helps retain blood in the head and chest. The manoeuvre also calls for pilots to adjust their breathing habits when experiencing heightened g-forces. Repeated at two- to three-second intervals, pilots will inhale, followed by a sharp burst of air to close a part of the larynx called the glottis. This increases the pressure in the chest and blood flow to the brain.

Pilots can use anti-g straining manoeuvres to limit the likelihood of experiencing G-LOC

The control room was continuously monitoring us during our centrifuge session

Flight data, such as g-force levels, is sent from the gondola to the control room

Pilots are allocated their own anti-g suits for the duration of their training

Q&A Flight Lieutenant Nathan Shawyer

Joining the Royal Air Force in 2009, Flight Lieutenant Shawyer graduated to the frontline in 2017 as an operational Tornado pilot. Now in training to progress to a Typhoon pilot, he has experienced first-hand the immense centrifugal force he can expect up in the air

How does the new RAF Cranwell centrifuge compare to the now retired Farnborough training facility?
This facility [Cranwell] is a lot better, definitely better; the fact that you are in control and there is a simulation in front of you, you can decide on the onset rate and how aggressive you are with your hands and the amount of gs that are given to you. It means that you are less of a passenger and more in control, which then makes the g tolerance a bit better.

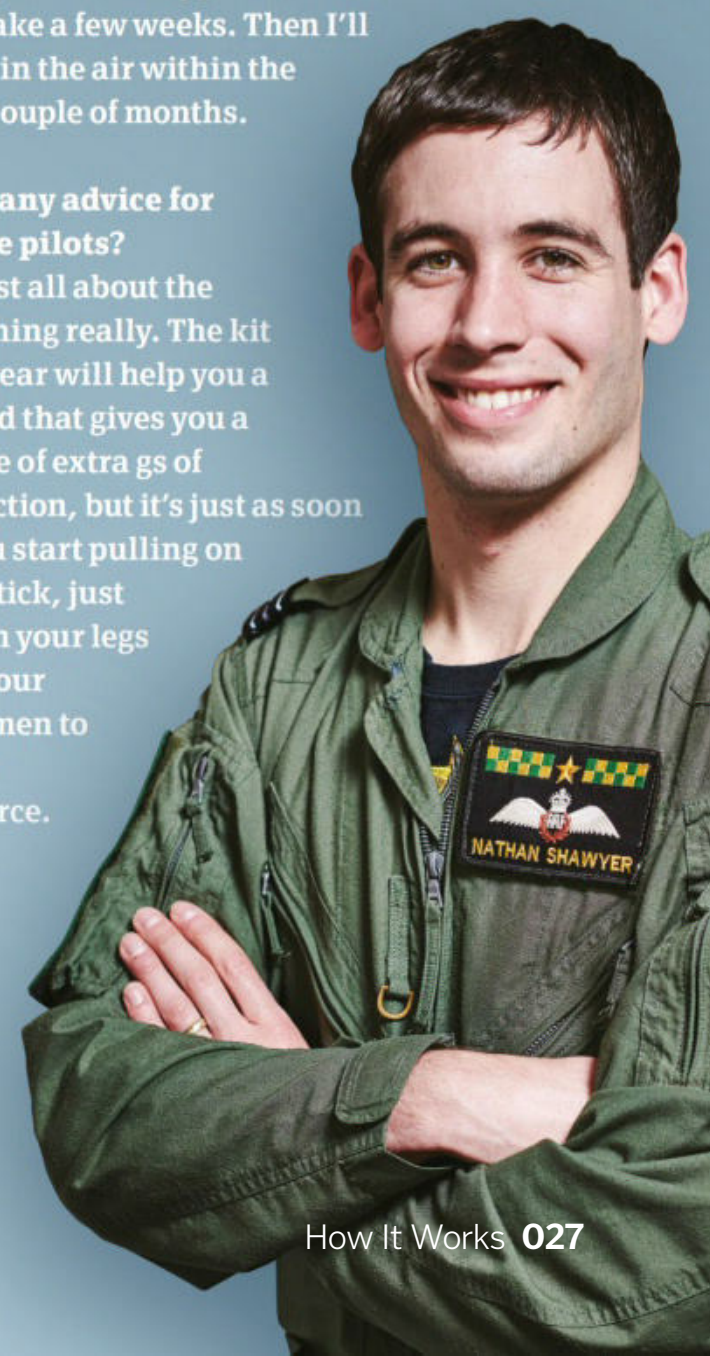
Control room will limit the amount of g you can pull, but if your limit is say, four and a half to five gs, you can pull as much as you want up to that limit and that's where they will sustain you. Also, if you're in any discomfort and you need to back off, you physically back off yourself and the machine will wind down. When you're rolling right, left, pushing back and forward, flying the aircraft around, it's giving you that g-force, which makes it more realistic for us, rather than just being strapped in sent up to several gs and held there.

How would you describe the feeling of reaching nine gs?
It's the weight aspect really. So at nine gs you weigh nine times as much, which is not just on one location on the body, everywhere is being pressed down. So obviously breathing and just staying awake proves quite challenging because the blood is draining from your head, but also the physical discomfort that brings in terms of your arms and your legs all having to push and strain against the immense force that's pushing down on top of the body.

How do you do contend with flying under such high levels of g-force?
That's why this [centrifuge] is brilliant: being able to train and get the techniques right, in terms of the breathing and straining the muscles groups. So, by the time you actually get to fly the Typhoon at those sort of g levels, you've got spare mental capacity to deal with tasks, such as targeting or flying the aircraft to a much greater degree and not having to worry too much about your own physiology because that should be happening almost subconsciously.

How much centrifuge training will you need to do to move onto the Typhoon?
I've done a run [on the centrifuge] up to seven and a half gs and another up to nine gs, so I'll move on in a few days. I'll do a ground school element first and some simulator work to get to grips with the Typhoon and that will take a few weeks. Then I'll be up in the air within the next couple of months.

Have any advice for future pilots?
It's just all about the clenching really. The kit you wear will help you a lot and that gives you a couple of extra gs of protection, but it's just as soon as you start pulling on that stick, just clench your legs and your abdomen to resist the force.



UNDERWATER EXPLORERS

Welcome aboard! How private submersibles are taking us to incredible new depths of the ocean

Words by **James Horton**

The oceans serve as Earth's largest habitat and are home to a phenomenal array of life. As well as discovering this rich diversity, exploring the depths allows us to peel back the curtain on another world. Mere centimetres beneath the waves corals bloom, fish graze, cephalopods hunt and crustaceans battle. But few of us ever get the opportunity to venture deeper, down where the pressure is too much for our unprotected bodies to endure and the light fades away leaving the water an inky black. At these extreme depths fantastical creatures begin to appear. First the swordfish, then the angler fish, then for the lucky few, the elusive giant squid. Until recently a private citizen could do little but dream about seeing such sights for themselves. But there are now some astounding vehicles that have unlocked the potential of the deep blue. We are in the era of the private submersible, which not only lets civilians peruse the depths at their leisure, it's letting them do it in style.

"At these extreme depths fantastical creatures begin to appear"

These manned vehicles are escorted to their dive sites by other vessels, but once set loose under the water they are able to roam independently. Many of the companies that are selling such technologies also offer pilot training, meaning the private operator can take full control of their new vehicle. The variety already on offer is astounding. In this feature we'll uncover shallow pleasure cruisers, hardier research vessels and even a submersible that can reach the very deepest point on the ocean floor. Yes that's right: you can now buy a vehicle that will allow you to replicate a feat that has so far only been achieved by three people in history. So read on and get saving, because these pleasures don't come cheap. But it'd be hard to argue that they aren't worth the money.

Bottom dweller

Meet the Triton 36000/2, an emerging veteran of the deep

The latest trialled and tested Triton model is a juggernaut of a submersible. Built to endure the punishing pressures of the oceans depths repeated times, the vehicle is currently undergoing a pilgrimage to prove its mettle. Under the control of a private owner, Triton is touring the world on a quest to escort its pilot to the deepest point of the world's five oceans. As the sole manned submersible of the Five Deeps Expedition, at the time of writing Triton has already touched down at the bottom of the Atlantic, Southern and Indian Oceans, and will tackle the Pacific and Arctic depths later this year. Upon its completion of this record-breaking mission the submersible, its launch vessel and accompanying craft will become available to a private owner. They can all be yours for just $48.7 million (around £37.7 million).

TRITON 36000/2

DEPTH RATING:
11,000 metres
MAX CREW:
2
LIFE SUPPORT (HRS):
16 (standard)
96 (emergency)
MAX SPEED:
3 knots

Protection
A 90mm thick and 99.933 per cent truly spherical hull protects the crew from a crushing 1,100 bars of pressure.

Safety measures
Multiple redundant ascension systems and 12 separate batteries ensure that the Triton will always be able to return to the surface.

Viewports
Carefully positioned acrylic viewports allow the crew unobstructed forward and downward views of their surroundings.

Freedom of movement
The submersible can easily ascend, descend and pivot with the help of versatile motors.

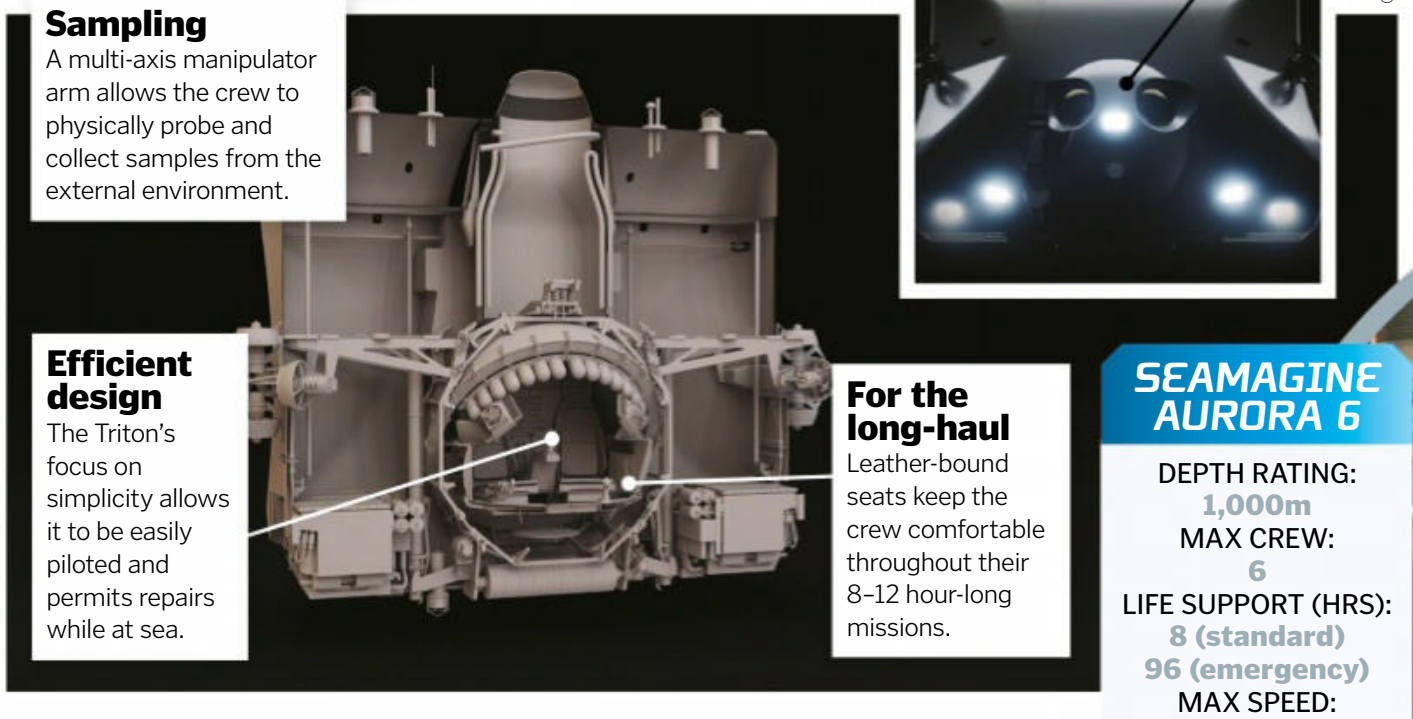
Piercing the dark
High-output LEDs illuminate the absolute darkness of the ocean floor.

© Triton Sub

Sampling
A multi-axis manipulator arm allows the crew to physically probe and collect samples from the external environment.

Efficient design
The Triton's focus on simplicity allows it to be easily piloted and permits repairs while at sea.

For the long-haul
Leather-bound seats keep the crew comfortable throughout their 8–12 hour-long missions.



Record-breaker

In March 2012, film-maker James Cameron touched down at the deepest point in the world's ocean – near the very bottom of the Mariana Trench. Just two others had achieved the feat before, and Cameron was the first pilot to make the descent solo. Cameron was housed in the state-of-the-art Deepsea Challenger submersible, which was able to capture valuable data. The vehicle itself was an engineering marvel, requiring the team to invent a new composite of foam – to help the vehicle ascend – and develop novel fluid-compensated electronics to produce working thrusters. Equipped with a robotic arm, a 2.5-metre tower of LEDs, two robotic vehicles and 3D cameras, Challenger was able to bring a heap of material back to the surface. The mission was a resounding success.

Titanic and *Avatar* film director James Cameron piloted the Deepsea Challenger in 2012

© Getty

Ocean tourer

Dubbed an 'underwater lounge', the Aurora 6 boasts two recliners positioned behind the pilot's chair, a guest area seating three more behind that, and even a lavatory at the rear. Passengers get near-complete views of their environment from inside acrylic globes that form the protective hull. As the vessel tours the ocean, its occupants are treated to an immersive experience akin to an underwater glass tunnel you could find at an aquarium. Except the Aurora can dive to 1,000 metres and explore the darkened depths below.

The Aurora 6 is designed to offer five passengers tantalising views in blissful comfort

© Seamag ne

SEAMAGINE AURORA 6

DEPTH RATING:
1,000m
MAX CREW:
6
LIFE SUPPORT (HRS):
8 (standard)
96 (emergency)
MAX SPEED:
3 knots

Underwater luxury

Cruise along in unrivalled splendour beneath the ocean tides

Sometimes a massive yacht just isn't enough. For those fortunate few who are lucky enough to tour the seas on their own private vessels, a pleasure cruise beneath the waves undoubtedly holds as much appeal as the sights to see above it. Fortunately, the NEYK submarine is ready and able to fill this purpose. With a modular design that can be easily modified to fit its owner's specifications and desires, the NEYK can host a crew of up to 20 people. The airplane-style hull is also peppered with viewports, allowing the passengers to sit back and drink in the sights hidden beneath the waves.

Enjoy all mod cons while exploring underwater

360-degree vision
The pilot can gain a wide view via the top viewport.

Surveying
A high-resolution 3D sonar scanning system can complement the viewports to help the pilot visualise the vessel's surroundings.

Portability
A retractable undercarriage allows the NEYK to ascend and descend ramps from launch vessels under its own power.

Rising up
The submarine can return to the surface by inflating four air balloons attached to the hull.

Sensors
Extra lights, cameras, night vision equipment and radar can all be equipped to the NEYK's dome.

Sea views
The nose can be modified to a glass front to improve passengers' viewing.

Thrust
Two powerful 200kW electric motors quietly drive the propellers, providing the crew with a tranquil cruise.

Streamlined
Its teardrop structure helps the slender vessel surge through the water at up to 15 knots.

Modular comfort
The heavily customisable interior can be altered to accommodate a large crew, additional furniture or extra equipment.

NEYK LUXURY SUB

DEPTH RATING:
900 metres
MAX CREW:
20
LIFE SUPPORT (HRS):
125
(12 passengers)
MAX SPEED:
15 knots
(11 knots surfaced)

TRITON 1000/2

DEPTH RATING:
305 metres
MAX CREW:
2
LIFE SUPPORT (HRS):
10
MAX SPEED:
3 knots

Shallow dive

You needn't travel far underwater to enjoy the splendour of marine life. As any keen snorkeler or scuba diver could testify, the bustling marine cities of coral reefs and the diverse array of predators and prey that swarm the shallows offer some truly mesmerising sights. Triton's adventure sub, the 1000/2 model, facilitates long stays at these enchanting locations for a pilot and their passenger. Equipped to easily plummet through the shallows, the vessel can playfully scour coastal waters from dawn until dusk. For the media-minded, the vehicle can also tolerate a hefty payload of cameras for capturing the marine environment and footage of sunken wrecks. A mechanical arm mounted on its front also enables the crew to interact with their surroundings and gather samples to bring back to the surface.

Deep water researcher

The Titan is an innovative deep sea science vessel

Data collection
Multiple 4K cameras, data tablets and a laser scanner enable the craft to capture deep-sea data for scientific research.

Sight inspection
The Titan's arsenal of equipment and large viewport make it perfect for surveying underwater wrecks.

The Cyclops
Titan boasts the largest viewport of any deep-sea submersible, providing immersive views for its crew.

Easy docking
Integrated landing provisions allow the submersible to dock after a dive without assistance from a scuba team.

© OceanGate

OCEANGATE TITAN

DEPTH RATING:
4,000 metres
MAX CREW:
5
LIFE SUPPORT (HRS):
8 (standard)
96 (emergency)
MAX SPEED:
3 knots

Sports sub

No matter the hobby, there are always those who seek to take it to a greater extreme. Enter the HiPer Sub 2, a retro-looking submersible that resembles a sports car-turned amphibian vehicle straight out of a classic James Bond movie. The vessel can travel at a respectable six knots to a depth of 100 metres, but its true madness and thrill lies in its ability to safely tumble, roll, swerve, vertically ascend and descend and generally zip around erratically under the sea. Its designers profess to the sensation being like piloting a fighter jet, and if that wasn't exciting enough, the controls can be easily switched between passengers, letting all aboard (there's a 4-crew version, too) take a turn at the wheel. As far as accessibility goes, this submersible also takes the crown. Rather than being only suitable for a super yacht, it can be easily towed behind a car and smaller marine craft.

U-BOAT WORX HIPER SUB

DEPTH RATING:
100 metres
MAX CREW:
2
LIFE SUPPORT (HRS):
6
MAX SPEED:
6 knots

The HiPer Sub series are purpose built to perform tricks under the water

© U-boat Worx

Layers of the oceans

What inhabits the bright shallows and dark deep?

Epipelagic Zone
The majority of plant and animal marine life reside in the highest layer of ocean.

0–200m
The shallows of the ocean are known as the Epipelagic or the 'Sunlight' Zone.

200–1,000m
Home of the 'Twilight Zone', referred to as the Mesopelagic Zone by ocean scientists.

1,000–4,000m
This gloomy region is the last to be reached by any sunlight.

Bathypelagic Zone
The crushing pressures found at this depth prevent many submersibles from reaching it.

4,000–6,000m
The Abyssopelagic or simply 'Abyssal' Zone is in perpetual darkness.

6,000m+
The world's deepest oceanic trenches are an alien place than be reached only by extremely specialised vessels.

Hadopelagic Zone
The deepest region is home to spectacular animals such as tube worms, viperfish and ghostly-looking octopus.

Tornado chaser

What makes the TIV2 vehicle fit to survive the full force of 200mph storm winds?

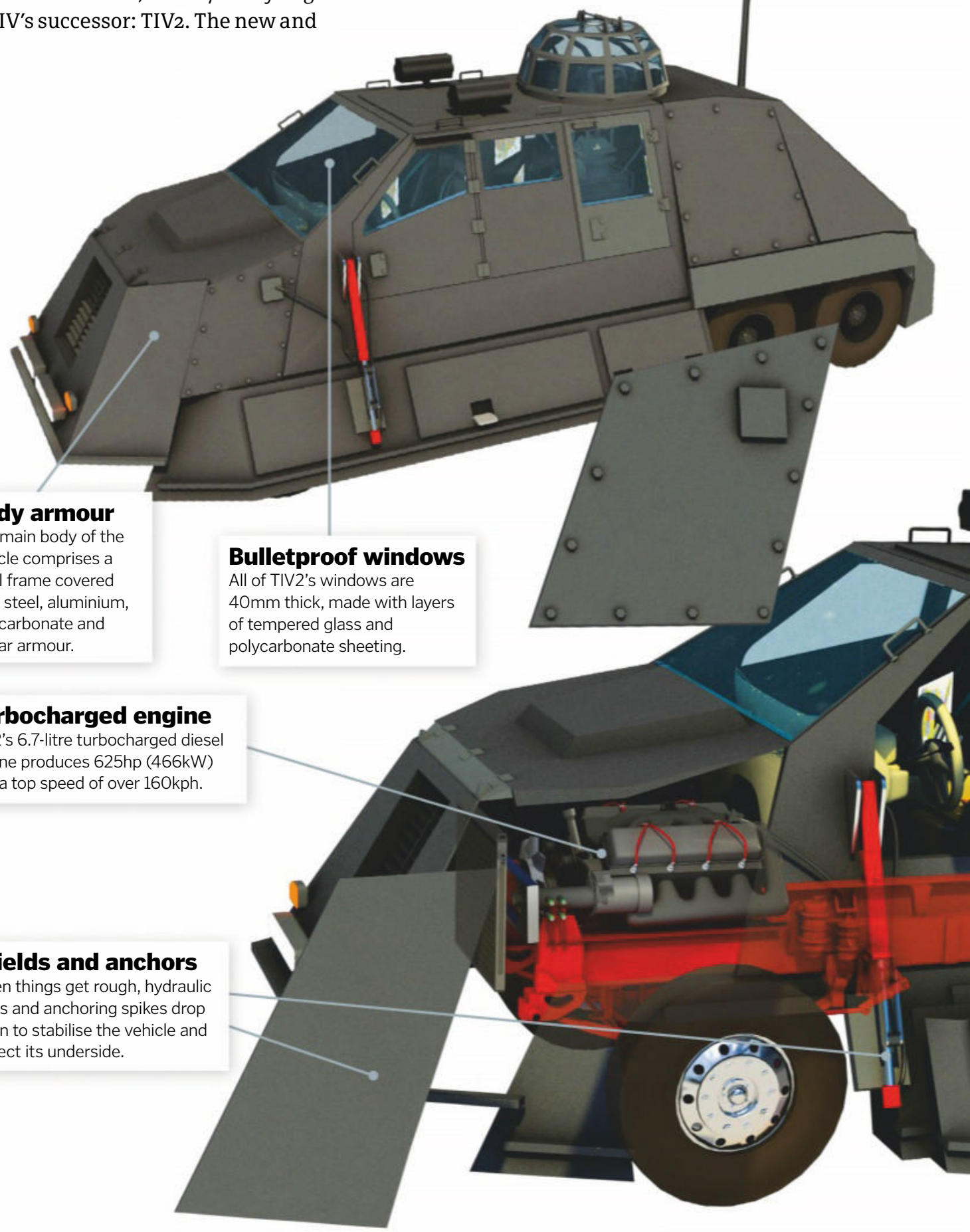
When a big storm is about to hit, most people think only of their safety, taking shelter or evacuating the area. Not the storm chasers; these fearless – some would say reckless – weather watchers get as close to it as possible. Storm-chasing season in the US' Tornado Alley peaks in May and June, with chasers flocking from all over the globe to experience the wild conditions in the region. Motives range from scientific research and obtaining media footage to sheer thrill-seeking, but most chasers share the same ultimate goal: witnessing a tornado in action.

Director Sean Casey has created several films about extreme weather and storm chasing. Casey realised early on that normal cars couldn't get as close to the action as he wanted to be, so he used the cab and chassis of a truck as the base for a purpose-built storm vehicle: the Tornado Intercept Vehicle (TIV). Covered in armour plating and equipped with bulletproof windows and hydraulic claws that anchored it to the ground, TIV could keep filmmakers safe during a moderate tornado while still providing a great view of the storm raging outside.

Still not satisfied, in 2007 Casey began work on TIV's successor: TIV2. The new and improved tornado vehicle took months of work and a team of 40 welders. Once completed, TIV2 allowed film crews to venture right into the hearts of storms and tornadoes and come out again in one piece. It experienced several mechanical issues during its first few years of service and underwent further modifications, going on to be used for multiple television series and IMAX films.

Built for a battering

TIV2 is designed to cope with anything a violent storm can throw at it



Body armour
The main body of the vehicle comprises a steel frame covered with steel, aluminium, polycarbonate and Kevlar armour.

Bulletproof windows
All of TIV2's windows are 40mm thick, made with layers of tempered glass and polycarbonate sheeting.

Turbocharged engine
TIV2's 6.7-litre turbocharged diesel engine produces 625hp (466kW) and a top speed of over 160kph.

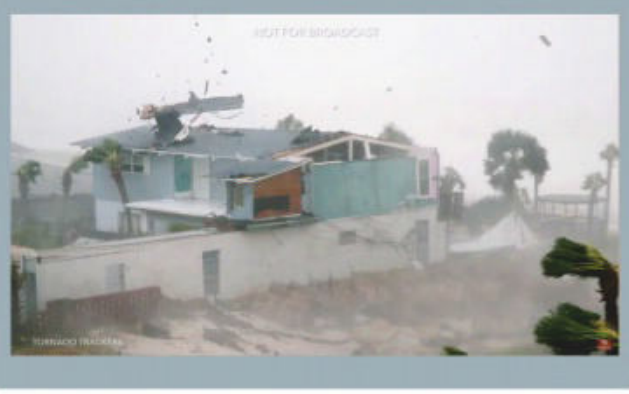
Shields and anchors
When things get rough, hydraulic skirts and anchoring spikes drop down to stabilise the vehicle and protect its underside.

Watching Michael at work

In October 2018, Central America and the US were hit by Storm Michael, one of the strongest and most intense Atlantic hurricanes on record. A Category 4 hurricane, Michael reached top wind speeds of 250 kilometres per hour. In case the wind wasn't enough, storm surges and floods followed in the wake of the hurricane. In total, the storm caused 72 fatalities and an estimated $25.1 billion (around £19.5 billion) of damage.

Rather than fleeing from the hurricane, many storm chasers loaded up their vehicles and headed out to capture the catastrophic power of Storm Michael as it travelled inland from its landfall point in Florida. Stationed in a multi-storey car parks, a storm chasing team known as the Tornado Trackers managed to film the havoc Michael wreaked at Panama City Beach, Florida, on 4K film cameras.

Storm chasers watched as the powerful hurricane tore buildings apart



What if you were sucked into a tornado?

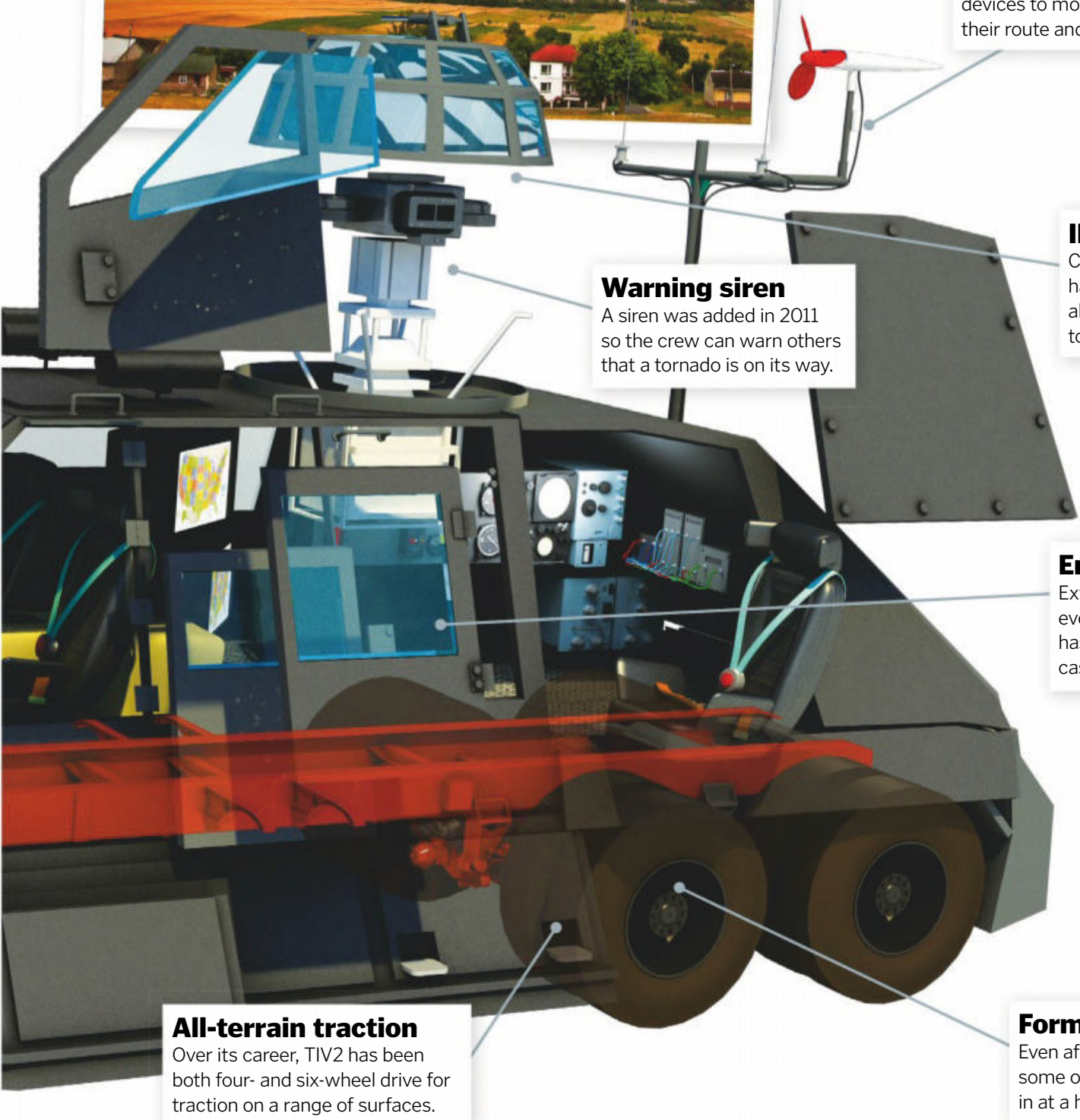
Unless you seek it out (which you definitely shouldn't), your chances of being sucked into a tornado are tiny. For the unlucky few who do find themselves in the path of a strong twister without the protection of a building or storm vehicle, the combination of winds strong enough to rip asphalt from the roads, debris spiralling at high speed and reduced oxygen can prove deadly.

Several animals and people – including babies – have been picked up by weak tornadoes, buffeted around for a few seconds and then deposited a short distance away. With little debris to injure them, they survived with a few bruises and the memory of an intense adrenaline rush.

A trip in a tornado is more likely to be deadly than exhilarating

TIV2 isn't alone – other storm chasers and scientists have their own modified vehicles

WARNING
As exciting as it looks, remember that storm-chasing is dangerous – don't attempt it without an expert present



Weather watching gear
The team inside TIV2 use a number of devices to monitor the weather, plan their route and contact other groups.

IMAX turret
Crucial for filming, TIV2 has a rotating turret that allows a camera operator to get the perfect shot.

Warning siren
A siren was added in 2011 so the crew can warn others that a tornado is on its way.

Emergency exits
Extra doors mean that every seat in the vehicle has an exit close by in case of an emergency.

All-terrain traction
Over its career, TIV2 has been both four- and six-wheel drive for traction on a range of surfaces.

Formidable weight
Even after measures to remove some of its bulk, TIV2 weighs in at a hefty 6,500kg.

5 FACTS ABOUT STORM CHASING ESSENTIALS

1 Vehicle safety
Storm chasers look for two main qualities in their vehicles: speed and weight. Fast cars provide quick getaways, while heavy cars stand the best chance of withstanding storm winds.

2 A full fuel tank
No matter how well-suited, a vehicle will still get you into serious trouble if it runs out of fuel when you need to get away from a dangerous situation.

3 Thorough training
Storm chasers have expert knowledge of the weather they're heading towards, the equipment they'll need to track and film it, and when to abandon a chase.

4 A reliable team
There's safety in numbers, and with more people you can allocate tasks like driving, weather tracking and filming so you don't miss a second of the storm.

5 Essential equipment
Storm chasing vehicles are always packed with the necessary equipment, from emergency lighting, maps and radios to high-quality cameras and snacks.

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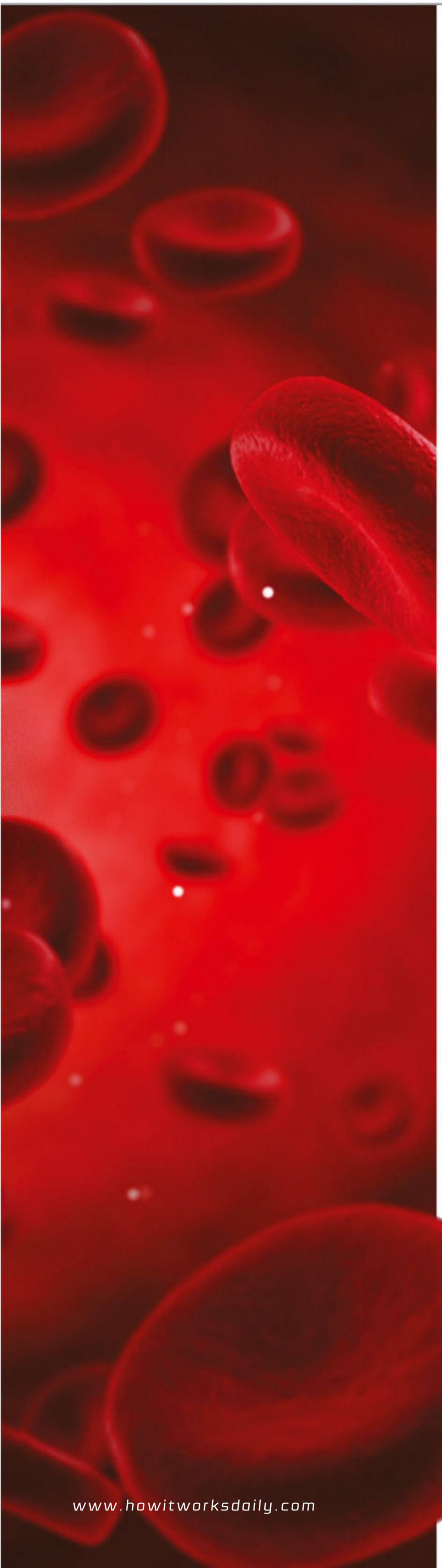
WHAT YOUR BLOOD DOES



The body's internal river system transports nutrients, delivers oxygen and disposes of waste without being told to by the brain

Words by **Amy Grisdale**

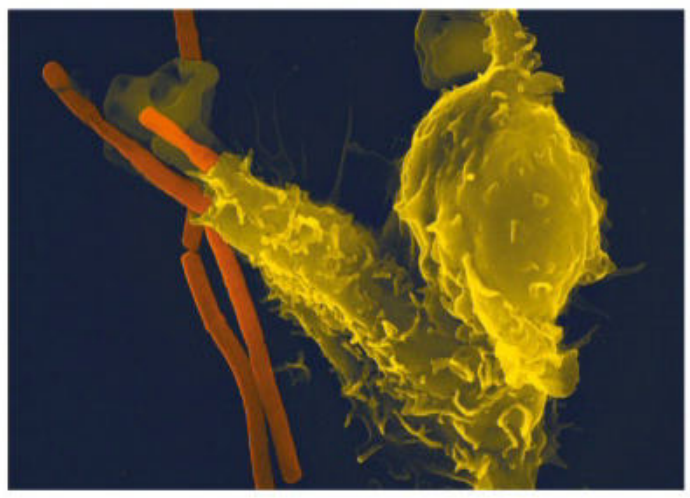
The heart is the engine of the circulatory system. Heart muscle is myogenic, which means it contracts without the aid of a signal from the brain. A nerve called the sinoatrial nerve acts like a clock, causing spontaneous and rhythmic beats. These muscles prompt the four chambers inside the heart to tighten and relax to force blood through the heart, driving oxygenated blood to the body's organs and pushing oxygen-low flow to the lungs.

Blood has an immense number of functions that are essential for survival. It supplies oxygen to the entire body and takes away carbon dioxide. It carries nutrients that have been digested in the gut, as well as body-regulating hormones. It regulates the body's temperature and helps seal wounds in the skin. Additionally, white blood cells protect against bacteria and foreign materials that have found their way into the bloodstream.

More than a gallon of this fluid runs through your veins, arteries and capillaries. It's made up of four components. Red blood cells account for up to 45 per cent of the total volume. White blood cells represent only one per cent of the blood's contents. Platelets are fragments of cells that help blood clot. Even though platelets are numerous in blood, their small size means they only make up a fraction of blood volume. The fluid component is plasma, which is 90 per cent water. The remaining 10 per cent is made up of dissolved gases, nutrients and waste products.

> "Blood has a huge number of functions that are essential for survival"

The first known blood cells arose 500 million years ago in primitive sponges. These animals were probably the first multicellular beings and had blood-like cells that engulfed foreign particles. This type of cell is called a phagocyte and humans have approximately 33 billion of them throughout their circulatory system. Blood has evolved to become extremely complex and differs even between members of the same species. In dogs, over 12 different blood types have been identified, while humans have eight – and receiving the wrong kind of blood can prove to be fatal.



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A white blood cell engulfs a deadly anthrax baterium that has entered the bloodstream

Why so blue?

Octopuses have three hearts and need oxygen-rich blue blood to survive

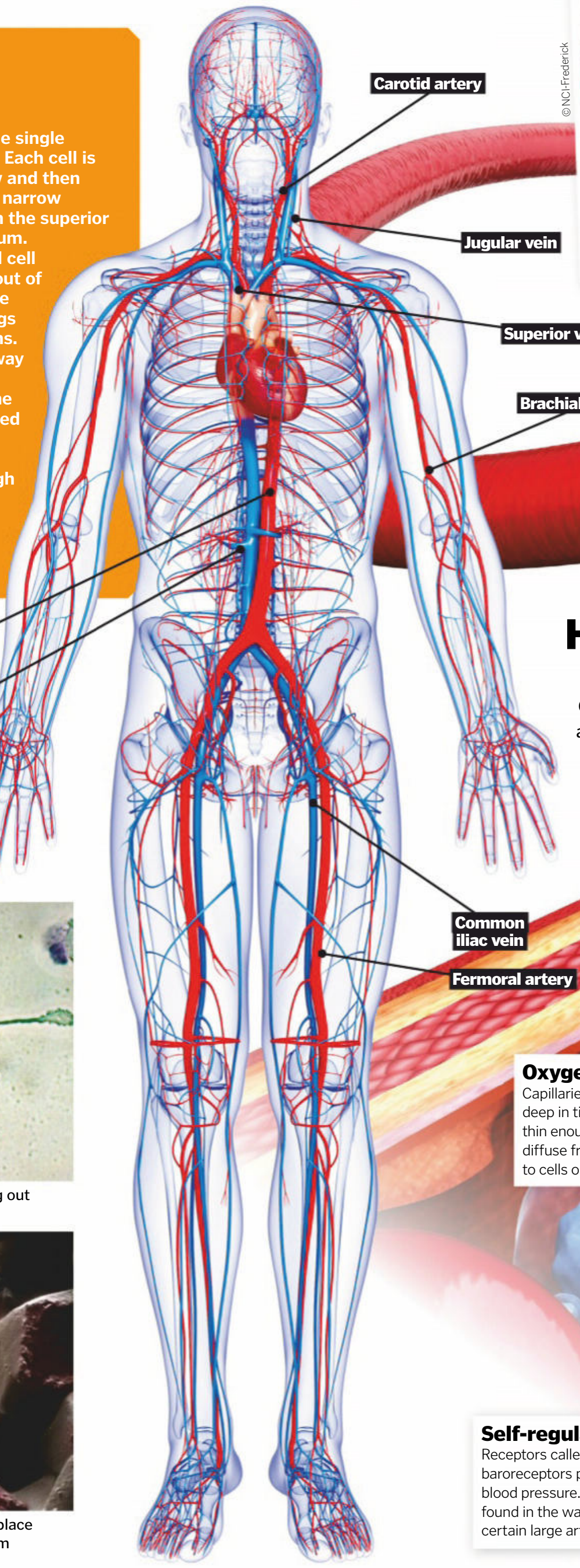
Octopus blood turns blue when it comes into contact with oxygen. Unlike mammalian blood, which is full of iron-based protein haemoglobin, marine invertebrate blood is rich in haemocyanin. This copper-based protein is highly effective in deep water where oxygen levels are low. It is colourless inside the body but oxidises when it hits air.

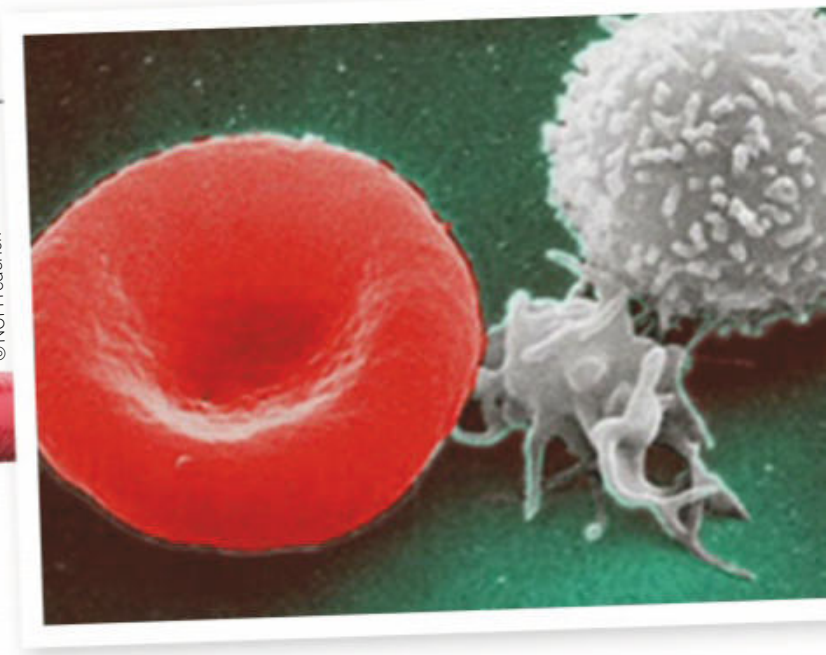
Haemocyanin binds with the oxygen the animal needs for respiration. In cold temperatures oxygen stays bound to the protein, starving the muscles of the gases that they need to function. Antarctic octopuses overcome this with haemocyanin that is less attractive to oxygen than that of tropical octopuses. This allows oxygen to travel around the body and be delivered where it is required.

© Getty

Journey of a blood cell

Red blood cells exist with the single purpose of carrying oxygen. Each cell is created within bone marrow and then travels to the heart through narrow capillaries. It moves through the superior vena cava into the right atrium. Contractions push the blood cell into the right ventricle and out of the heart. It travels down the pulmonary artery to the lungs where gas exchange happens. Red blood cells make their way back to the heart via the pulmonary vein and enter the left atrium. Cells are squeezed into the left ventricle then pumped out through the aorta. They then flow through the circulatory system and drop oxygen off around the body until they die around 120 days later.





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A red blood cell alongside a barbed thrombocyte and a round leukocyte

Arteries, capillaries and veins

The heart pumps blood through arteries into complex networks of tiny capillaries then into veins, the blood vessels with the lowest pressure.

How blood flows

Our blood needs to be able to move up, down and all around

Oxygen transfer

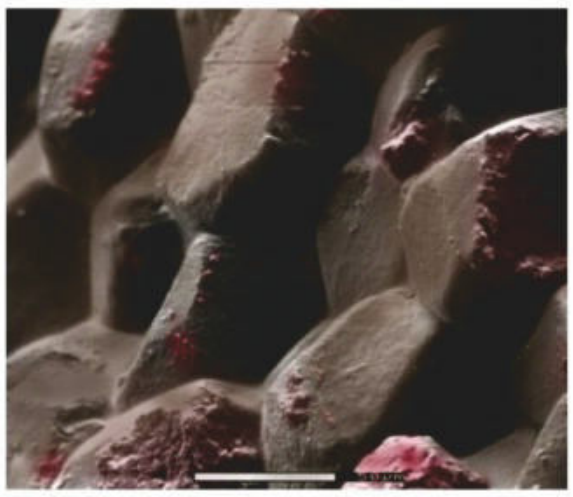
Capillaries are all embedded deep in tissue. Their walls are thin enough for oxygen to diffuse from red blood cells to cells on the other side.

Self-regulation

Receptors called baroreceptors police blood pressure. They are found in the walls of certain large arteries.

© Obli

A macrophage of a mouse stretching out to trap harmful molecules



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A closeup of bone marrow, the birthplace of cells that make up the bloodstream

> *"White blood cells represent only one per cent of the blood's contents"*

Pressure
Blood exerts force on vessel walls. Blood flows from areas of high pressure to low pressure.

Life cycle of blood cells

The incredible journey of one of our most important cells

Recycling
Remnants of blood cells are used again. Haemoglobin breaks down and returns to the bone marrow to make new cells.

Bone marrow birth
More than 2 million red blood cells are made in our bone marrow every second.

Maturity
Reticulocytes are immature forms of red blood cells. They are already in the bloodstream when they finish growing.

End of days
Phagocytes called macrophages engulf red blood cells that are at the end of their life cycles.

Short shelf life
Red blood cells don't last forever. They become worn out and die within about four months.

Two-way gas exchange
Haemoglobin is the protein in a red blood cell that carries oxygen, but it also binds to carbon dioxide to take it back to the lungs.

Components of blood

Our bloodstreams have specific ingredients that work together to keep us alive

Red blood cells
Each holding up to four oxygen molecules, red blood cells can transport up to 25 sextillion (25 followed by 21 zeroes) oxygen molecules around the human body at any one time.

Platelets
These miniscule cells pick up signals from damaged blood vessels and rush to the site of injury, spreading across the abrasion.

Monocytes
Representing less than one per cent of all blood cells, monocytes are like army reserves that are called up to assist with healing.

Lymphocytes
This type of white blood cell makes antibodies, kills dangerous cells and controls the response of the immune system to foreign substances.

Granulocytes
These come in three types: eosinophils deal with parasitic infections, basophils initiate inflammatory responses and neutrophils are first responders to microbial infection.

Eosinophil

Basophil

Neutrophil

> *"Red blood cells transport up to 25 sextillion oxygen molecules around the human body"*

Inside your hand

The evolution of this dextrous appendage has been one of the keys to human success

For most of us, hands are pieces of equipment taken for granted. We grab, manoeuvre, tap, gesture and touch without thinking about the astounding complexity and accuracy of the movements. Fold down just one finger and everyday tasks become much harder, because over human history the hand has become highly specialised.

Standing on two legs freed up the arms of our ancestors for a greater range of uses. It's believed that the tool use of early hominids began the transition from an ape-like appendage to the modern hand; those with hands better suited to gripping stones were able to smash animal bones and access the nutritious marrow inside.

Other primates like orangutans have hands similar in shape to ours, but the human hand is in a league of its own in terms of dexterity. While our primate relatives have short thumbs and long fingers for grabbing and swinging from branches, humans have evolved shorter fingers and considerably longer and more mobile thumbs. This anatomical change has resulted in two fundamental types of human grip: the power grip and the precision grip. Early in human history these grips would have been useful primarily for throwing and clubbing, but today they allow us to master everything from the pole vault to intricate needlework.

Like other apes, humans have flattened fingernails rather than claws. Claws provide grip for climbing and traction while running, but they impede fine movements. As well as allowing careful manipulation of objects, primate fingernails are still useful for gripping, pinching and scratching.

Thumbs up

Much of the precision and versatility of our hands is thanks to our opposable thumbs, a rarity in the animal kingdom. Humans can move their long thumbs in multiple directions and touch them to every other finger on the hand, producing a firm grip and the ability to handle objects delicately.

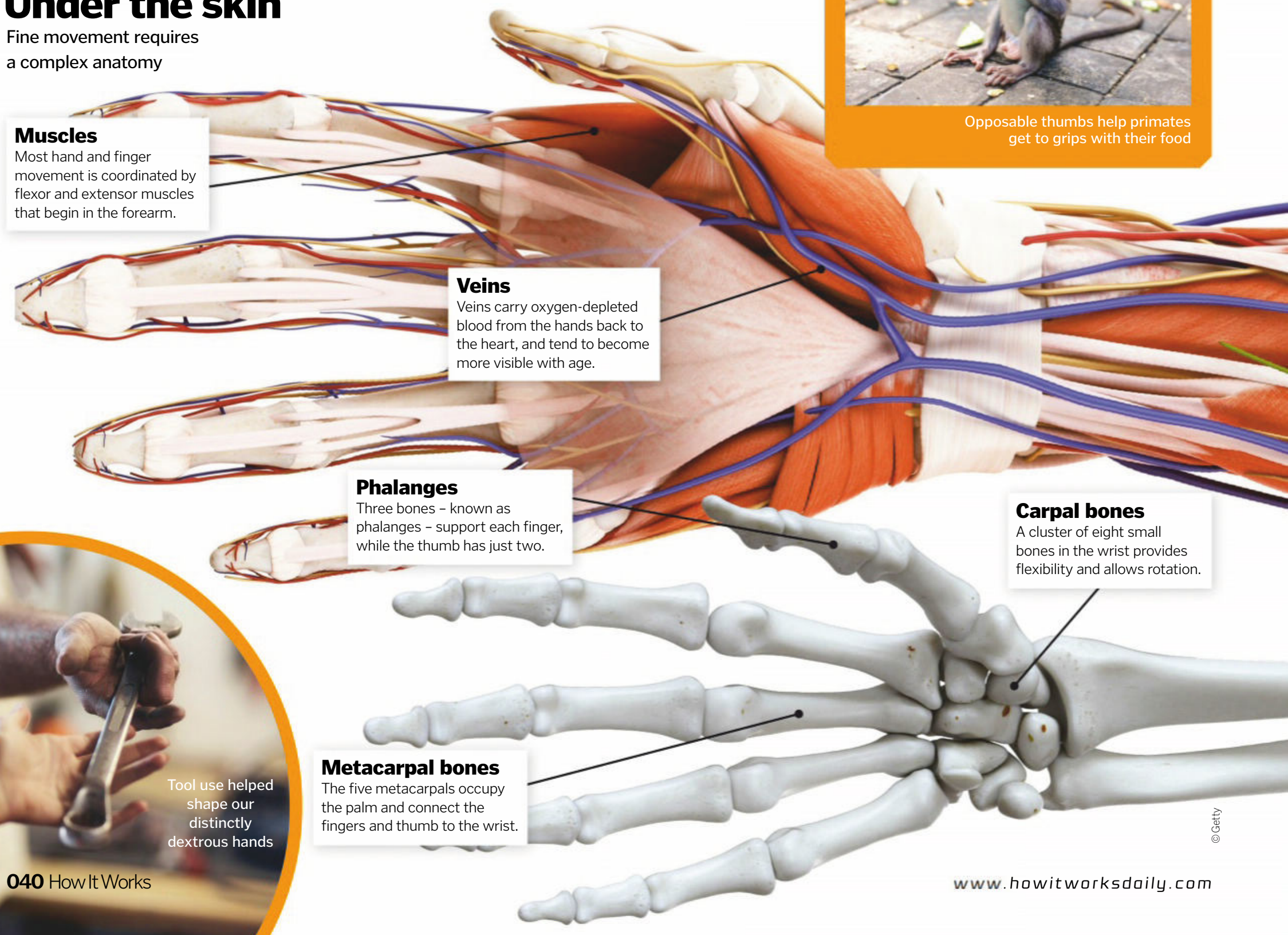
While humans' are the most mobile, we're not the only ones with opposable thumbs. Great apes have both opposable thumbs and opposable big toes, useful for gathering food and building nests. Lesser apes and Old World monkeys also have opposable thumbs. They keep them out of the way when they're swinging through the trees, but employ them for tasks like picking fruit and grooming.

Other tree-dwelling species like koalas and even some species of arboreal frog have mobile thumbs. Opossums have them on their hind legs, working with their prehensile tails to provide stability.

Opposable thumbs help primates get to grips with their food

Under the skin

Fine movement requires a complex anatomy



Muscles
Most hand and finger movement is coordinated by flexor and extensor muscles that begin in the forearm.

Veins
Veins carry oxygen-depleted blood from the hands back to the heart, and tend to become more visible with age.

Phalanges
Three bones – known as phalanges – support each finger, while the thumb has just two.

Carpal bones
A cluster of eight small bones in the wrist provides flexibility and allows rotation.

Metacarpal bones
The five metacarpals occupy the palm and connect the fingers and thumb to the wrist.

Tool use helped shape our distinctly dextrous hands

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SUPER SENSES

In the animal kingdom, five senses are nowhere near enough. Check out these incredible animal superpowers and how they're used for survival of the fittest

Words by **Ella Carter Sutton**

SMELL

Some bear species are able to sniff out a meal from several miles away!

Bears have amazingly adapted noses and brains to enable them to sniff out mates, avoid danger and – most importantly – forage for food.

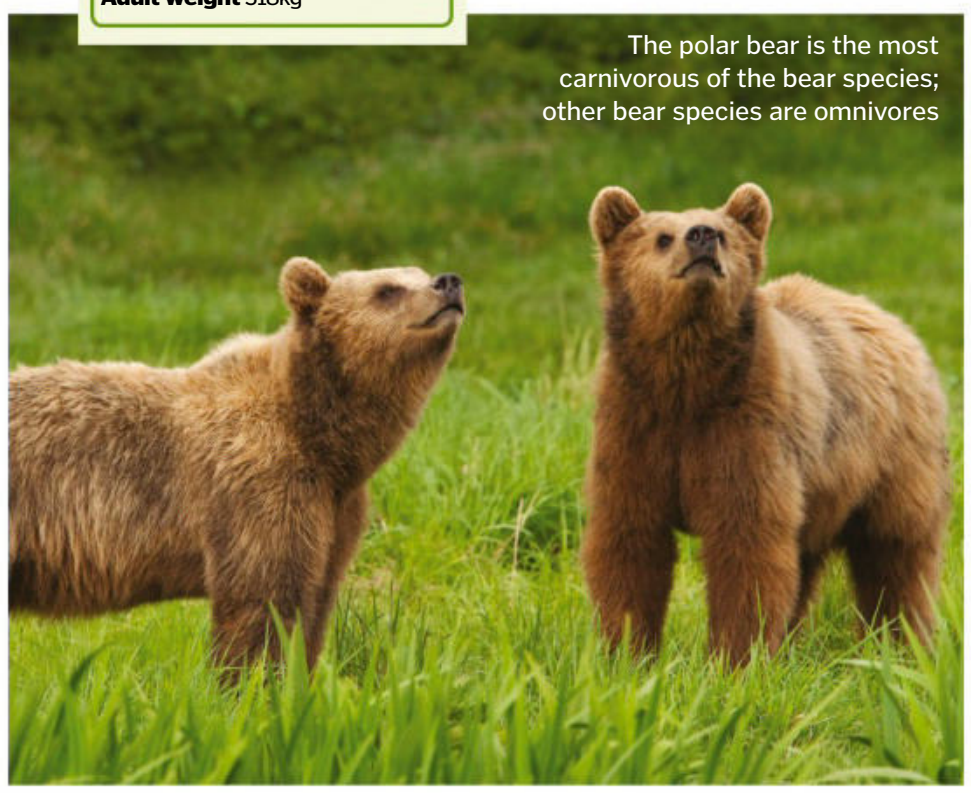
A bear can smell accurately for several reasons. First, their noses are positively huge. This provides a large surface area for smell receptors, and the more receptors, the more sensitive the sense of smell.

The other advantages of a bear's nose is that they have specialised muscles that allow them to manipulate their nose movements – this helps them follow scent trails accurately over long distances to locate tasty morsels for dinner.

The area of the brain that interprets scent, known as the olfactory bulb, is also five times larger in a bear than the same organ in a human brain, despite the bear's brain being one third of the size of a human's. This means extra processing power for a phenomenal nose performance. For example, polar bears have been known to swim 160 kilometres to reach a female that's ready to breed!

BROWN BEAR
Ursus arctos
Class Mammalia

Territory Forests and mountains of northern North America, Europe and Asia
Diet Fish, rodents, vegetation
Lifespan 25 years
Adult weight 318kg



The polar bear is the most carnivorous of the bear species; other bear species are omnivores

Rats have two methods of smelling their environment and detecting changes in their ratty friends

SMELL

With two smelling methods, rats are true super sniffers

Rodents have highly adapted noses that are super-sensitive. It's thought that this is an adaptation for these small furry critters to find food, as a rodent's diet is typically very varied. But although it's true many rats and mice seem to only think with their stomach, food is by no means the only thing they're sniffing. Particular chemicals found in all types of bodily secretions can alert rats to the presence of predators – meaning they can literally smell danger. They can also determine hormonal changes in other animals as well as environmental signals, just from sniffing the air and sometimes sampling the scent with a lick.

Rats have two types of scent organs. As they breathe in air through the nose, it wafts over a patch of skin heavily populated with smell cells, called olfactory receptors. These receptors detect the scent and then pass the information to the rat's brain. This patch of skin is very sensitive indeed, and rats have 1,207 olfactory receptor genes – by comparison, us humans have just 350 genes that code for sniffing receptors.

The other method of smelling is through an organ known as the vomeronasal organ, or VNO, and is primarily used for detecting pheromones. This organ sits inside the rat's nose, and when the critter smells or tastes something, scent molecules dissolve in mucus and are passed to the VNO where the information is sent to the brain. Using this organ helps the rat detect changes in other rats around it. For example, a male rat is unable to mate with a female rat unless he can smell the hormonal information that tells him she is ready.

SIGHT

The mantis shrimp has the most complex eyes in the animal kingdom

MANTIS SHRIMP
Stomatopoda
Class Malacostraca

Territory
Tropical and subtropical waters
Diet Small crustaceans, sea snails and shellfish
Lifespan 20 years
Adult weight 600g

These little crustaceans – there are over 550 species of mantis shrimp – mostly live in the Indian and Pacific Oceans. These fierce predators can pack a literal punch, but their incredible eyesight is even more impressive. Two large eyes are perched on its head, which can move independently of one another. Each has 'trinocular vision' – each eye can focus on objects with three separate regions to perceive depth and distance.

Within the mantis shrimp's brilliant bogglers are millions of photoreceptors – tiny light-detecting cells. Us humans have just three types of these cells, but mantis shrimp have 12 to 16 types of photoreceptors. It was once thought that this meant that they could see in amazing Technicolor, but it's now known that these receptors actually work to help the shrimp see different wavelengths of light, notably ultraviolet.

The chameleon is able to look forward and backward at once

The eyes of a chameleon are truly extraordinary. Unlike us humans, who have two front-facing eyes, the eyes of a chameleon can move independently of one another. The two cone-shaped sockets, that give this endearing lizard a particularly boggle-eyed look, are actually one big eyelid that opens wide enough for just the pupil to see out. Each eye can move in every direction, without the chameleon having to move its head. What is amazing is when the eyes come together. When a chameleon spots its prey, it will turn its head to face the bug of choice, which enables it to bring both eyes together and focus directly on the tasty morsel. This is known as binocular vision, where the images from each eye 'overlap' to provide a greater perception of depth and movement. This adaptation enables the chameleon to strike effectively to score a tasty mouthful.

Telephoto eyes
The lizard's eyes work like a telephoto camera lens, able to 'zoom in' on prey.

Judging distance
The anatomical structure of chameleon eyes allows each eye to independently judge distance.

Protected peepers
The chameleon's eyelid is fused to the eye, with scaly skin for protection.

Constant awareness
Being able see 360 degrees at once lets the chameleon stay on its guard against predators.

TASTE

Pigs have sensitive tongues

As animals that are famed for not being very fussy eaters, both wild and domestic pigs are known to have very sensitive tongues, making them super-tasters Being omnivores, having a good sense of taste is important in selecting what's good and what's bad to eat. Pigs know what they like to eat, and they can also taste what's bad, poisonous or dangerous to eat – an obvious advantage when foraging for food.

Humans have around 9,000 to 10,000 taste buds on our tongues to help us decide what is good to eat. By comparison, pigs have around 19,000.

The catfish has taste buds all over its body

Living at the bottom of dark, murky waters, the sense of sight isn't really of much use to a catfish. Instead, these fish have evolved an amazing sense of taste so that they can easily find food by simply sampling the water around them. Taste buds are present all over the fish's body, totalling about 250,000 – quite impressive for the smallest of catfish that are just 15 centimetres long.

The highest concentration of taste buds is on the catfish's moustache-like whiskers, known as barbels. These are highly sensitive feelers and the fish uses them to great effect to taste the environment around it and search for food, which could either be live fish, or some tasty, slowly decaying carcass, depending on the species' preferences. The catfish can then use its barbels to home in on the location. These appendages are so sensitive that some fish are able to detect particular types of protein in the water at tiny concentrations – sometimes as low as one to 100 micrograms per litre.

The super sense of smelling chemicals

Many animals, mostly invertebrates, have cells that are sort of like taste buds and olfactory receptors, but work in different ways and can also perform other functions. Chemoreceptors are receptor cells that are able to detect certain chemicals in the environment, whether that be molecules that are for smelling or tasting, or for detecting hormones and pheromones from other animals.

Amazing sixth senses

A huge array of animals are able to see wavelengths of light that are invisible to our human eyes. One of these is ultraviolet (UV) light – part of the electromagnetic spectrum that we simply can't see. Some species of fish, insects, birds and plenty of mammals such as caribou and even humble cats and dogs are able to see UV light.

Caribou (also known as reindeer) rely on their UV sight during their yearly migrations across the frozen tundra. This sense enables them to sniff out lichens, their major source of food on their long journey, as well as distinguish the urine of predators against the white snow. The urine is UV-absorbent while the snow is UV-reflective, giving reindeer the best chance of avoiding a tussle with hungry animal hunters.

Infrared

Some amazing animals can see the heat emitted from their prey's body

The infrared section of the electromagnetic spectrum is invisible to us, but animals such many snakes, vampire bats and some insects are able to see infrared light. Snakes use infrared radiation from the bodies of their warm-blooded prey to see a 'heat map', enabling them to hunt in any conditions, light or dark.

In-built compass

These animals can find their way home, without even knowing the way

This amazing super sense is used for direction – animals such as humpback whales, pigeons and salmon are thought to use this to find their way home on their epic migrations. In the case of the humpback, magnetite in their bodies allows them to follow magnetic bands on the ocean floor – like a built-in compass.

Natural radar

Dolphins use sound via echolocation to naviage their environment

Dolphins, whales and even bats use this amazing sense to both navigate and hunt. It involves sending out a sound and then analysing the sound waves that return having bounced off nearby objects. It's thought that this sense may provide the animals with a three-dimensional view of the world around them.

Sensing electricity

Some critters can detect the tiny electrical currents that run through nature

Electroreception is the ability to sense natural electrical signals, exhibited by animals such as sharks and the duck-billed platypus. Sharks have amazing organs called ampullae of Lorenzini that enable them to sense prey moving in the water. Platypuses have similar pores in their bills that aid them when swimming in the dark.

Owl ears
Ears are rather large, slit-like openings that rest beneath the feathers at the edge of the facial dish.

Silent wings
The wing feathers are serrated, this allows near silent flight so the owl can hear its prey.

Dish of feathers
The great grey owl's dish of feathers is very pronounced – this is because it relies so heavily on its hearing.

Legs and claws
Long legs allow the owl to bomb into the snow, and sharp claws grasp prey tight.

GREAT GREY OWL
Strix nebulosa
Class Aves

Territory North America, northern Europe and northern Asia
Diet Mostly rodents
Lifespan 12 years
Adult weight 800–1500g

HEARING

These owls can hear prey over 100m away, through 45cm-deep snow

The great grey owl is a feisty, feathery hunter. It eats small mice and other rodents that live in its Arctic home, and often has to source its meals through a layer of snow or in the inky dead of the frozen night. Luckily, this owl's hearing is so acute that it never has to go hungry.

A combination of super-sensitive hearing and amazing physiological adaptations make this owl's hunting technique a precision affair. The bird's ears are tiny holes found under a huge dish of expertly placed feathers. The ears are placed at slightly different positions on each side of the head, so that sound enters the ears at slightly different angles and at different volumes. This is an adaptation that helps the owl to pinpoint the exact location of the sounds it hears – it creates a sound-map of the area and is then able to 'zoom in' on the creature making the noise. The facial dish of feathers acts like antennae. The shape of the dish of feathers guides sound waves into the owl's ears, enabling it to hear minute noises of prey beneath the snow. Sometimes this can even be the heartbeat of a small rodent.

Once a great grey owl hears the tell-tale noises of prey, it homes in on the sound before swooping. The owl will keep listening acutely while on the wing in case the prey moves during its approach, all the while keeping a watchful ear out until its time to dive down and secure a meal.

These owl species are able to fly in complete silence – which has the important benefit of the prey getting little to no warning that the owl is approaching. Silent flight is also incredibly useful to ensure the owl can concentrate on listening for the prey's movement right up until the last second, unencumbered by the noise created by its own colossal wings.

Elephants hear with their feet

Elephants have often been known to make strange, sudden migrations that seemingly have no reason or purpose. However, it's now known that this quick change in direction is due to their incredible hearing, detecting the presence of falling rain, sometimes up to hundreds of miles away. They are able to hear this due to their ability to hear low-frequency sound, known as 'infrasound', which is between one and 20 Hertz. They can also pick up vibrations from other elephant herds running or stomping from a predatory threat miles in the distance.

Due to the nature of the long sound waves created by such low frequencies, this allows social herds and individuals to communicate over very long distances. The calls are so low that, as humans, it's totally out of our earshot. It is thought this ability caused animals in Sri Lanka and Thailand to hear the approach of the 2004 Indian Ocean tsunami. They were witnessed fleeing to safety before any human was aware of the incoming threat.

AFRICAN ELEPHANT
Loxodonta africana
Class Mammalia

Territory Africa
Diet Leaves, grass and fruit
Lifespan 70 years
Adult weight 6,000kg

Elephants can pick up vibrations from the movement of other herds many miles away

TOUCH

Crocodiles have had dozens of millions of years to adapt their sense of touch to become the perfect predator

NILE CROCODILE
Crocodylus niloticus
Class Reptilia

Territory Africa
Diet Mainly fish, will attack most other animals
Lifespan 45 years
Adult weight 227kg

Crocodiles have highly sensitive snouts to detect prey

When you think 'sensitive animal', crocodiles usually aren't the first creature to come to mind. Their armoured bodies, skull-crushing jaws and formidable teeth seem to be anything but sensitive, but these beasts also have to sense their environment just like the rest of us. On a croc's head and snout, there are raised black domes. There are a few of these all over the body too. They're known as integumentary sensory organs (or ISOs) and had baffled scientists for a long time. It was then discovered these dots are full of touch receptors, thus making a croc's nose more sensitive than a human fingertip. They are highly sensitive to pressure and vibration and let the animal sense prey moving in the water, feel for food and snatch a quick mouthful. Alligators also have ISOs, making them super-sensitive souls after all, at least in the nose department.

The yapok is the only living marsupial in which both sexes have a pouch

The yapok can see through its fingers

The tiny yapok, or water opossum, is an elusive marsupial that lives in the streams of the Amazon rainforest. It's nocturnal, and so only comes out in the dead of night to forage for food of fish and crustaceans. Nothing special about that, but, it's how this animal finds its way that gives it super-sense credentials!

The yapok has large front paws, which are very sensitive to touch, and it uses them, alongside its impressive whiskers, to feel its way in the inky blackness. The yapok does this by quite literally poking, prodding and nosing its way on. This water-dwelling critter's feet are also webbed, which help it to swim through its aquatic home. As it swims, the yapok's back legs provide propulsion and its front legs are outstretched, groping in front of it as it pursues its prey. The yapok's acute senses of hearing and smell are also very important when it comes to securing a square meal in the dark!

What was the CHERN

Chernobyl's new sarcophagus is shown in 2013

CHERNOBYL disaster?

Explore the site of the world's worst nuclear accident and discover how it has made an incredible recovery

Words by **Laura Mears**

When the Chernobyl nuclear reactor exploded in 1986, it released five per cent of its 200-ton radioactive core into the atmosphere. Radiation doses around the reactor rose from a safe average background level of two millisieverts (mSv) to over 20,000 mSv. It was the worst nuclear accident in history but, 30 years later, the environment has made a recovery that has astonished experts.

Immediately after the explosion, hundreds of plant staff and firefighters began the battle to contain the fallout. They flooded the reactor with up to 300 tons of water an hour, and even tried sending robots in to collect the flaming debris. To stem the blaze and block the radiation, pilots began to fly back and forth over the hole left by the explosion, dropping radiation-absorbing materials onto the exposed radioactive core: boron to absorb neutrons, dolomite to absorb heat, lead to block radiation and sand to weigh everything down. In total, they made roughly 1,800 flights, depositing 5,000 tons of materials.

Trees have flourished in the town of Pripyat in the years since the disaster

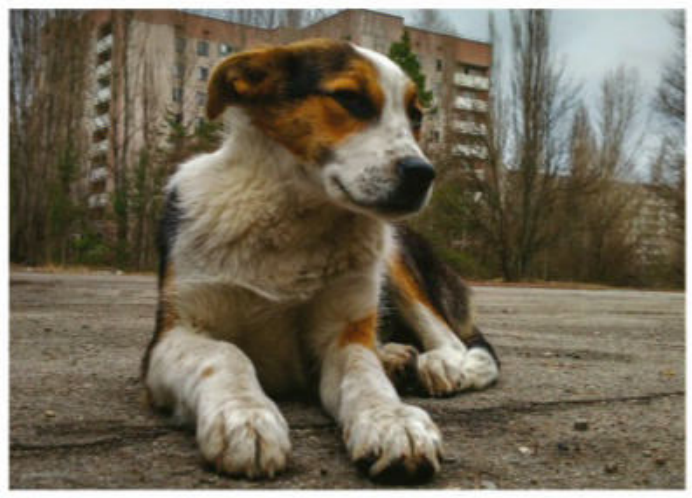
As they worked, dust and debris from the explosion climbed a kilometre into the air, and wind blew the fallout – radioactive dust and particles from the reactor that literally fell out of the sky – to the northwest. The most dangerous particles were caesium and iodine, both of which get into the food chain and can cause damage to DNA. The caesium-137 particles were large, so they didn't travel far. They collided with trees and buildings close to the power plant and coated the ground when it rained. They settled on skin and clothes, entered rivers and streams and seeped through the soil into the groundwater. This contamination covered an area spanning 200,000 square kilometres around the site.

The iodine-131 particles were smaller, allowing them to travel further. They rose high into the sky, scattering across Europe, with some traces reaching as far as the US and Japan.

The most immediate danger was to the people in the surrounding area. Those within 4,300 square kilometres were at risk of a potentially deadly lifetime radiation exposure of more than 350 mSv. Some of the 45,000 residents of the nearest town, Pripyat, had already received 50 mSv of radiation. So they, and more than 150,000 others in the surrounding area, had to evacuate. To this day, a 30-kilometre exclusion zone remains in force around the reactor, and it has been deemed too dangerous for humans to return to for at least 20,000 years.

As residents moved out, hundreds of thousands of workers moved in. These 'liquidators' washed radioactive dust from the streets with a thick liquid they called molasses. They bulldozed dead trees, buried broken equipment and knocked down contaminated buildings. They received radiation doses of between 100 and 500 mSv, putting their own health at risk. Of those that responded first, 237 became ill with acute radiation sickness. But, thanks to their work, radiation levels in the exclusion zone started to drop.

As time has passed, radioactive decay has made the exclusion zone even safer. Iodine-131 has a half-life of just eight days, and caesium-137 a half-life of 30 years. As the years go by, the danger from radiation is steadily falling.



The exclusion zone is home to hundreds of stray dogs, descended from abandoned pets

When the accident happened, the worst of the fallout hit the trees. They absorbed between 60 and 90 per cent of the radioactive cloud, experiencing radiation levels of 5 mSv an hour. As a result, 400 hectares of pine forest turned red and died, taking bees, butterflies and spiders with it. As rain washed the particles into the clay soil and new trees started to grow, the radioactive particles began to cycle through the ecosystem. They got into mushrooms on the forest floor, lichens on branches and from there into grazing animals like elk and deer. But, as the years since the disaster have passed, the forest has started to recover.

Birch and aspen trees have grown up in place of the damaged pines. They still take in radiation from the soil, but animals have started to return. Mouse and vole numbers have returned to normal, and larger animals are taking advantage of the empty spaces left by humans.

What caused the meltdown?

The night of the disaster, shift supervisor Aleksandr Akimov received orders to test reactor 4 at the Chernobyl Nuclear Power Plant. The plant worked by pumping water past hot nuclear fuel, creating steam which drove two turbines. His superiors wanted to know what would happen if the main electricity cut out, so they disabled some of the automatic safety features to conduct a test. Worried that it was a bad idea, Akimov resisted, but eventually he agreed to shut the system down for 20 seconds. However, the control rods that should have slowed the nuclear reactions actually caused the power to surge. The water in the reactor boiled, the pressure rose and the 1,000-ton reactor top broke free. This jammed the control rods, and the tubes containing the nuclear fuel started to crack. Then, the reactor exploded.

Helicopters dropped sand on the reactor in an attempt to contain the radiation

Timeline of Chernobyl

26 APRIL 1986
Reactor 4 at the Chernobyl nuclear power plant explodes, and firefighters battle to put out the blaze.

27 APRIL 1986
Helicopters make hundreds of trips over the reactor, dropping sand, lead and boron to absorb the radiation.

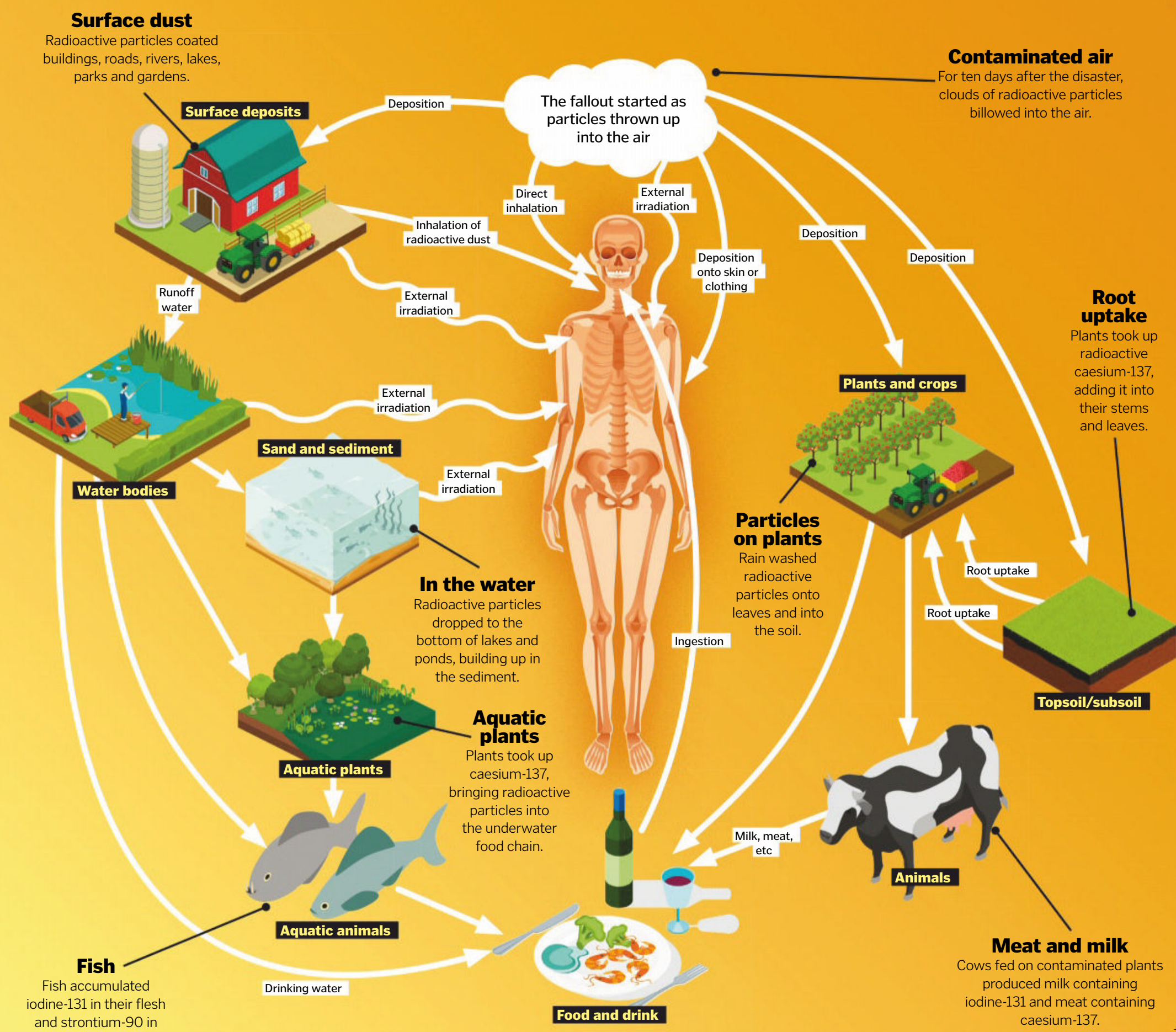
10 MAY 1986
Roughly two weeks later, the fire inside reactor 4 is finally extinguished.

NOVEMBER 1986
Liquidators complete construction of a concrete sarcophagus, covering the remains of the reactor.

1987–1991
Hundreds of thousands of liquidators work inside the exclusion zone to wash, bulldoze and bury contaminated buildings and trees.

HOW THE RADIATION SPREAD

Nuclear fallout moved through the environment in the days, weeks and months after the disaster



© Getty

1991
Chernobyl's three other nuclear reactors are still running. A fire in reactor 2 convinces authorities to shut it down.

2011
Radiation levels have dropped. Ukraine's Emergencies Ministry starts allowing tourists to visit.

2015
Census data reveals that elk, roe deer, red deer and wild boar are thriving inside the zone.

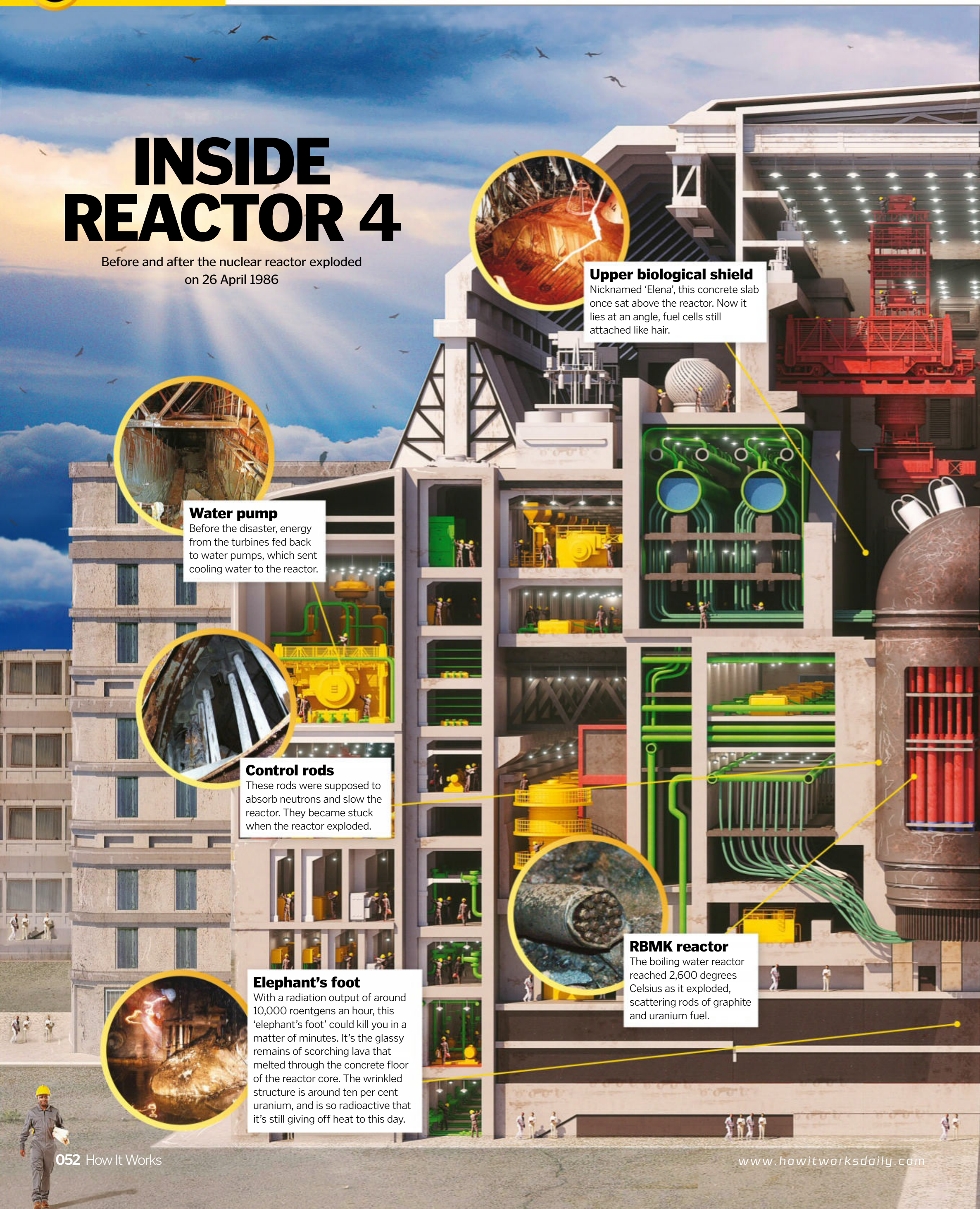
2016
The New Safe Confinement shelter slides into place over the old sarcophagus.

2018
The Chernobyl power plant gets a new lease of life with 4,000 new solar modules.

2019
Radiation levels just outside the New Safe Confinement now barely rival a dental X-ray.

INSIDE REACTOR 4

Before and after the nuclear reactor exploded on 26 April 1986



Upper biological shield
Nicknamed 'Elena', this concrete slab once sat above the reactor. Now it lies at an angle, fuel cells still attached like hair.

Water pump
Before the disaster, energy from the turbines fed back to water pumps, which sent cooling water to the reactor.

Control rods
These rods were supposed to absorb neutrons and slow the reactor. They became stuck when the reactor exploded.

RBMK reactor
The boiling water reactor reached 2,600 degrees Celsius as it exploded, scattering rods of graphite and uranium fuel.

Elephant's foot
With a radiation output of around 10,000 roentgens an hour, this 'elephant's foot' could kill you in a matter of minutes. It's the glassy remains of scorching lava that melted through the concrete floor of the reactor core. The wrinkled structure is around ten per cent uranium, and is so radioactive that it's still giving off heat to this day.

A herd of rare wild Przewalski's horses live among the abandoned buildings

Turbine
The working reactor used steam to drive two 500 MWe turbines, generating power.

Sand pile
After the explosion, helicopters dropped thousands of tons of sand, clay, lead and boron onto the reactor fire.

Explosive damage
A steam explosion blew through the building, and hot radioactive debris set fire to the roof.

Leftover fuel
The reactor contained around 200 tons of fuel when it exploded. Most of it is still there.

Fuel lava
Fuel, control rods and parts of the building melted together to form radioactive lavas called corium.

Pressure tubes
When the reactor was operational, cooling water moved around fuel-filled pressure tubes.

Radioactive rocks
Five types of lava leaked through the floor of the reactor: brown ceramics, black ceramics, slag, pumice and melted metal.

Enter the forest today and you'll find wild boar, brown bears, elk, roe deer, wolves, lynx and bison. Incredibly, numbers of endangered birds like black storks and white-tailed eagles are higher inside the exclusion zone than anywhere else in Ukraine.

Some areas of the forest are still hot with radiation. Here, animal tracks disappear, and birds go quiet. In these regions there are no organisms to break down falling leaves, so the litter on the forest floor is much thicker than it should be. To reduce the risk of fire, a herd of rare Przewalski's horses have been introduced into the zone to graze the forest floor. And, despite the radiation, they seem to be thriving.

With plants and animals flourishing across the exclusion zone, scientists have been working on ways to make the ground safe to farm again. Plants grown on contaminated soil take in caesium particles, and aren't yet safe for humans to eat. But researchers have discovered that potassium fertilisers can stop plants taking up radioactive particles. Straw around the base of the plants can then stop radiation getting back into the soil. Even simply ploughing the Earth can help to reduce hot spots by spreading out the radioactive particles. While each method only makes a small difference, combining them together could make the ground safe once again.

As the exclusion zone recovers, one major problem still remains. Reactor 4 is still there, along with 95 per cent of its radioactive fuel. And the cement sarcophagus built around it in the 1980s is crumbling. If it starts to collapse, it could release fresh clouds of radioactive dust into the air.

To stop this from happening, an international team completed a New Safe Confinement shelter in 2016 to contain the dust in case of collapse. Cranes will painstakingly disassemble the rubble so that we can start to remove the high-level waste and bury it safely. Beneath the shield, radiation levels still reach up to 500 mSv per hour. But outside, life is returning to normal. Standing directly on the new arch is now no more dangerous than having a dental X-ray. Thanks to intensive work over the past 30 years, the Chernobyl exclusion zone is starting to flourish again.

1,000 'self-settlers' returned to the zone to live on the radioactive land

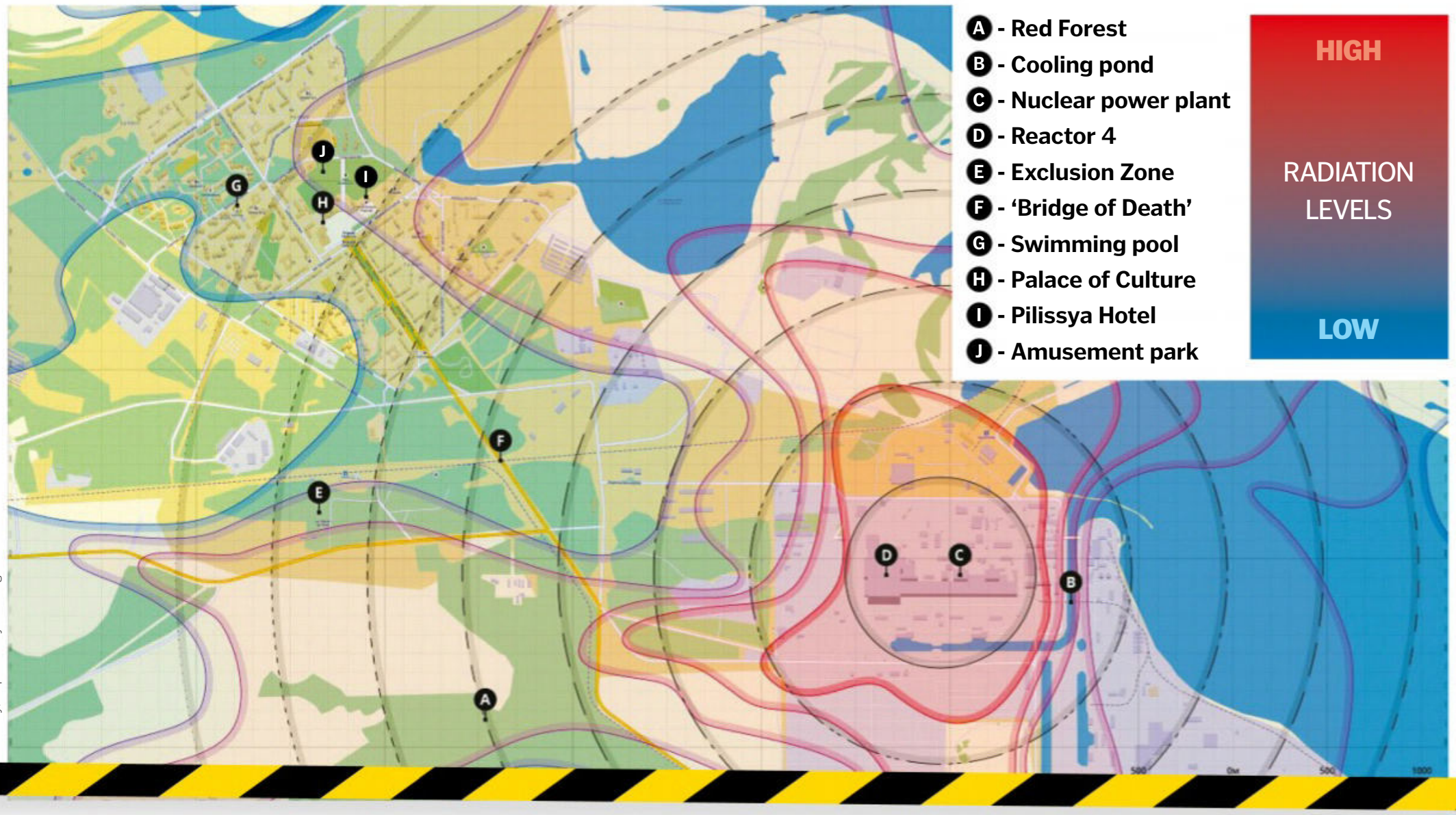
Wolves faced extinction in Europe, but they're thriving inside the exclusion zone

Why Chernobyl's wolves thrive

Forests still have some of the highest contamination of any ecosystem inside the exclusion zone. But that hasn't deterred the local wildlife. Some of Europe's most elusive mammals have made their homes between the trees, and they seem to be thriving. It seems European grey wolves would rather face low-level radiation than risk living alongside humans. There are now seven-times more wolves inside the zone than in protected areas nearby. Without us to interfere, they are free to chase deer, catch fish and even eat fruit from abandoned orchard trees. In fact, conditions are so good that scientists have spotted young males leaving the exclusion zone in search of more room.

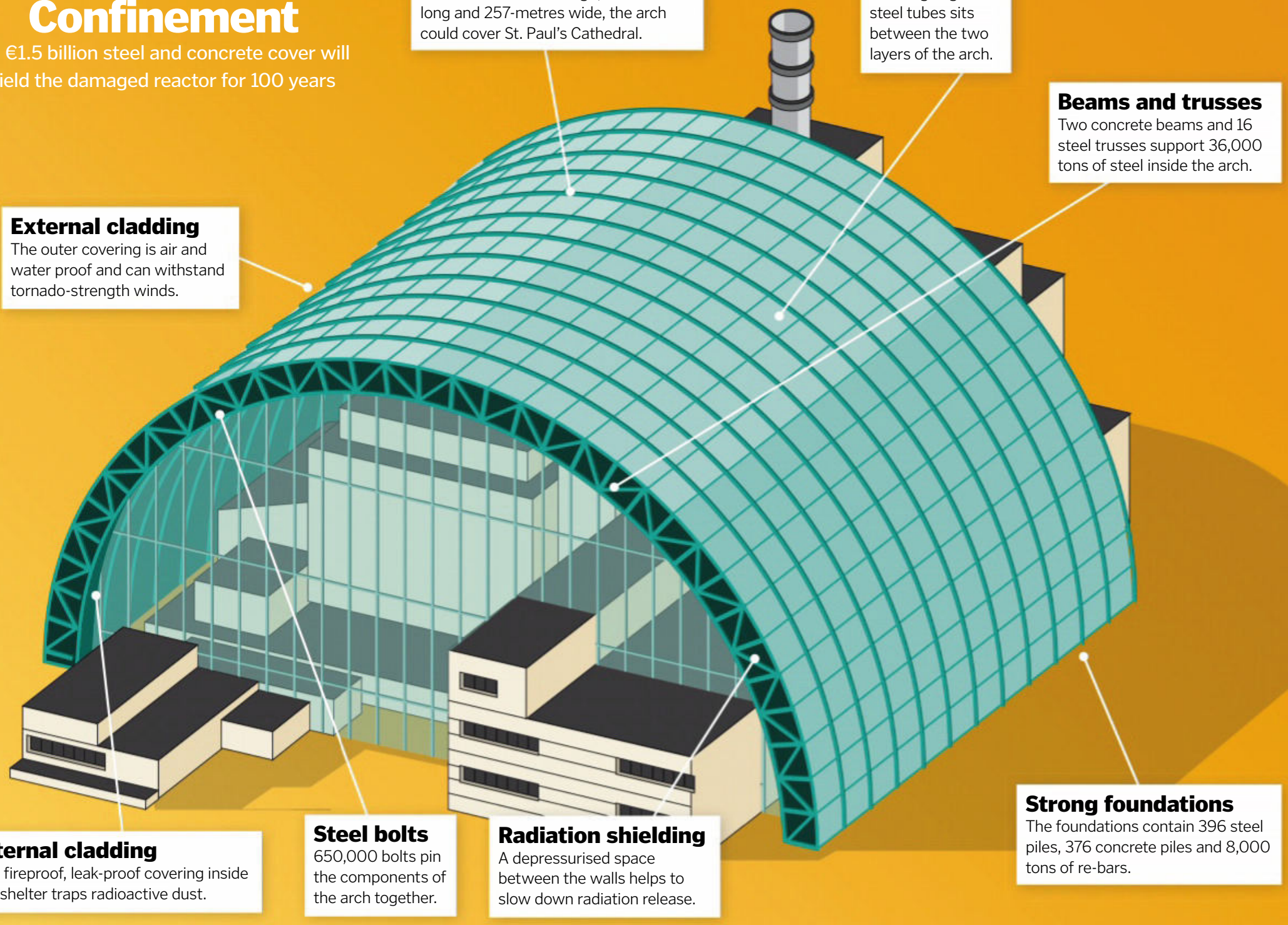
Exclusion zone radiation

This heat map reveals radiation levels inside the Chernobyl exclusion zone today



New Safe Confinement

This €1.5 billion steel and concrete cover will shield the damaged reactor for 100 years



Cathedral dimensions
At some 109-metres high, 162-metres long and 257-metres wide, the arch could cover St. Paul's Cathedral.

Steel lattice
A strong cage of steel tubes sits between the two layers of the arch.

Beams and trusses
Two concrete beams and 16 steel trusses support 36,000 tons of steel inside the arch.

External cladding
The outer covering is air and water proof and can withstand tornado-strength winds.

Internal cladding
The fireproof, leak-proof covering inside the shelter traps radioactive dust.

Steel bolts
650,000 bolts pin the components of the arch together.

Radiation shielding
A depressurised space between the walls helps to slow down radiation release.

Strong foundations
The foundations contain 396 steel piles, 376 concrete piles and 8,000 tons of re-bars.

WHAT REMAINS?

The disaster has had a lasting effect on the surrounding area

2,000 tons
of combustible materials like graphite and bitumen

4 tons
of radioactive dust and particles

630,000 cubic metres
of contaminated radioactive waste

1,300 tons
of hardened radioactive lava

200 tons
of unspent uranium fuel

43,000 cubic metres
of high-level waste containing spent nuclear fuel

1,500 roentgens
of radiation released every hour under the reactor

RISE OF THE CYBORGS

From medicine to computer interaction, how man and machine are becoming one

Words by **Mark Smith**

© Getty

DID YOU KNOW? *In 2001, American Jesse Sullivan became one of the world's first cyborgs after being fitted with an bionic arm*

Cybermen, Robocop, the Terminator: anyone familiar with science fiction will be all too aware of the concept of the cyborg.

The term was first used in 1960 by scientists Manfred Clynes and Nathan S. Kline in reference to an enhanced human that could survive in extraterrestrial environments. The cybernetic organism – to give it its full name – is a combination of biology and technology, a living being with computerised or mechanical implants designed to replace or enhance aspects of their existing body.

Cyborgs are no longer just found in films and comic books; they're very real, with enhancements in technology making it far easier, and safer, to graft technology into living creatures, from insects right up to human beings.

One of the side-effects of recent wars in the Middle East has been to put battlefield medicine back at the top of the research agenda, with advancements in motorised limbs creating replacement arms and legs that can respond to nerve impulses in the same way as a biological limb.

In 2016 the first-ever Cyborg Olympics took place in Switzerland, where some of this amazing tech was put to the test, from an exoskeleton – a frame that goes over your body and moves your limbs for you – designed by NASA that allowed a paraplegic to walk, to a motorised arm that one competitor was able to use for a range of tasks just by thinking about it, including completing a jigsaw puzzle and slicing a loaf of bread.

It's not just the need to replace injured or missing limbs that's driving things forward, but also trends. 'Bio hacking' is where people implant technology into their body.

Known as 'body hacks', these have included implanting magnets and near-field communication (NFC) chips, like those you use for wirelessly charging your phone, in fingers that can be programmed to open car doors or link to a website, or computer chips implanted in other parts of the body that can monitor things like temperature.

But many experts see the future of cyborgs being not just about improving our bodies with things like robotic arms, but also implanting things into our brains. Known as neurotech, this field of research is looking at how we can use things like neural memory implants as a cure for Alzheimer's disease, and how artificial intelligence can predict where body tremors caused by Parkinson's disease could occur.

"I controlled a robot hand: I was in New York and the hand was in Reading, but it felt like me, like I had another hand"

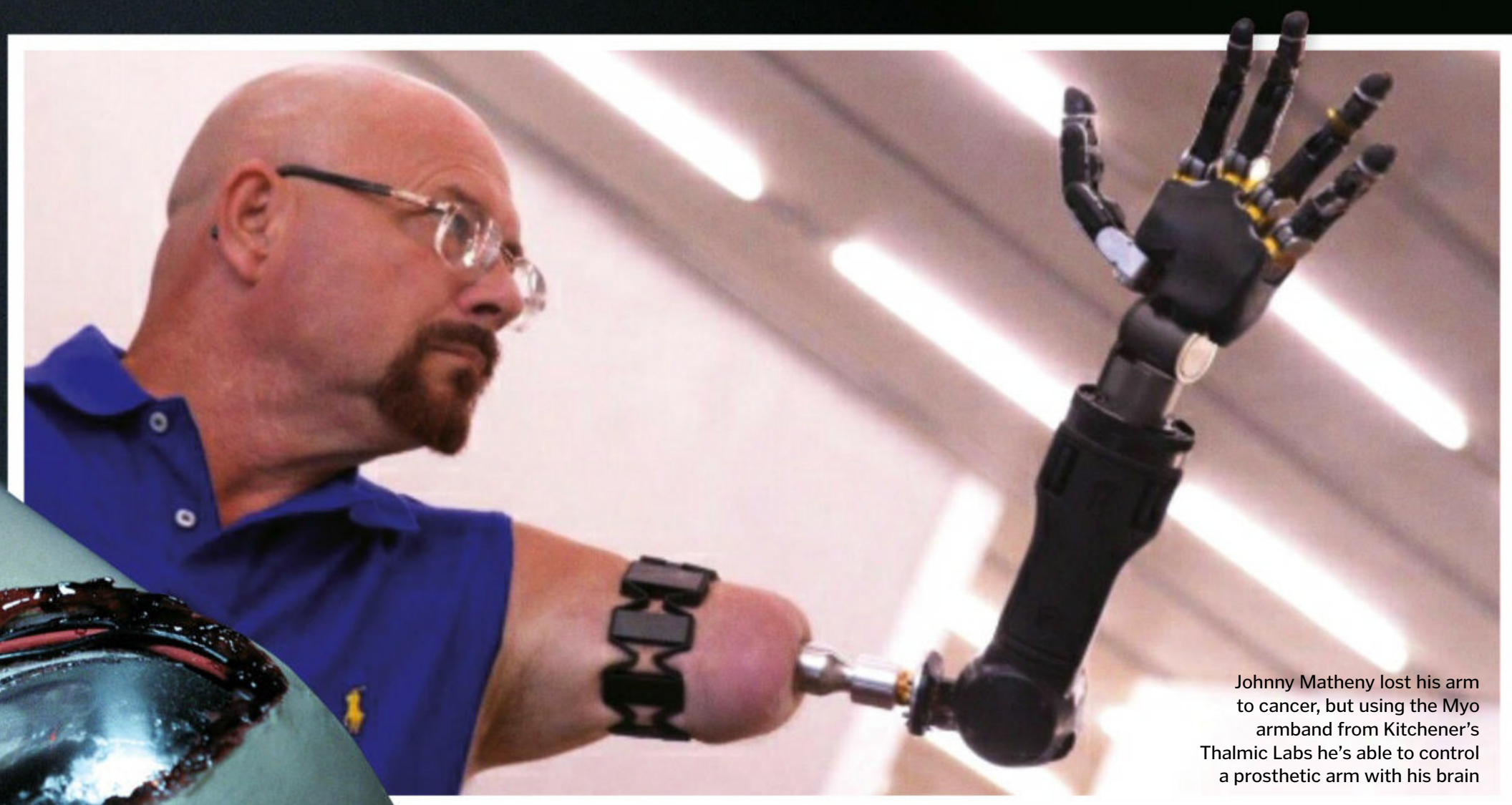
Testing for bugs

One controversial aspect of cybernetics is its use on insects. Scientists have successfully implanted electrodes into the brains of beetles, allowing them to 'hijack' the creatures' nervous systems and direct them via remote control.

Other studies have seen electrodes implanted directly into their muscles, which has created a more responsive insect-cybernetic hybrid.

One of the advantages of using insects is that their bodies are well designed. Indeed, robotics has often looked to the insect world for inspiration when designing machines. The work creates the possibility of swarms of bees being deployed on the battlefield, or worker ants being used in construction projects.

Scientists have implanted beetles with electrodes that allow them to be directed by remote control



Johnny Matheny lost his arm to cancer, but using the Myo armband from Kitchener's Thalmic Labs he's able to control a prosthetic arm with his brain

Q&A

Meet 'Mr Robot'

Kevin Warwick is an author, engineer, deputy vice-chancellor (research) at Coventry University, cyborg and all-round cyber guru

What is cybernetics being used for at the moment?
In terms of therapy there's quite a bit happening. Looking at people with cochlear implants, for instance, there are thousands and thousands. The last implant I had – the brain gate – has been used for four different people who are paralysed from the neck down. It allows them to control robotic hands – one woman has been able to feed herself. But it's mostly happening in the US.

How does it feel to have an implant?
It felt like me. Your brain adapts. I controlled a robot hand: I was in New York and the hand was in Reading, but it felt like me, like I had another hand. When it was gripping an object I could feel the pressure. It didn't feel weird. Where it did feel strange was when I thought about it afterwards and you start to think, 'wow'.

You've spoken in the past about cybernetics being needed to help us compete with the dangers of advanced AI, is that how you still feel?
Alan Turing said: "what is machine intelligence? It's something that's quite different than human intelligence." That was the point they made in *The Terminator*, 'you can't bargain with it' – it thinks differently to humans. Things have gone even faster than I thought they would in terms of AI. You've had people like Elon Musk and Steven Hawking talking about the things I was saying in the late 1990s, which is that AI could be dangerous if we go in the wrong direction with it.

What could the ultimate evolution of this tech look like?
Cures for Alzheimer's – there's a number of possibilities on that, but also the direct communication of thoughts. What we are – fundamentally – is a brain and a spinal column, and a lot of the reason we die is because something happens to our body, which is just there to carry our brain around. We might have robot bodies in the future. We should be doing more research into keeping our brains alive outside our bodies because then we don't even need to worry about things like cancer.

Known as 'captain cyborg', Warwick has implanted himself with cybernetic devices and is regarded as the world's leading expert

Enhancing the human body

From artificial hearts to new limbs, this is the tech no modern cyborg can be without

'Hearing colours'
Artist Neil Harbisson mounted an electronic antenna to the base of his skull that turns frequencies of light into vibrations his brain interprets as sound, allowing him to 'hear colour'.

Brain implant
Small computers can now be implanted into human brains to keep chronic seizures at bay.

Built-in compass
Scientists have created a chest implant that lets you sense which direction you're facing.

Replacement heart
American company BiVACOR is developing a bionic heart which propels blood around the body.

Limb replacements
Cybernetic replacements for missing or damaged arms and legs are giving amputees a whole new lease on life.

Back-pain treatment
A next-generation implant has been implanted deep into a patient's back to stimulate their spinal cord to override pain signals.

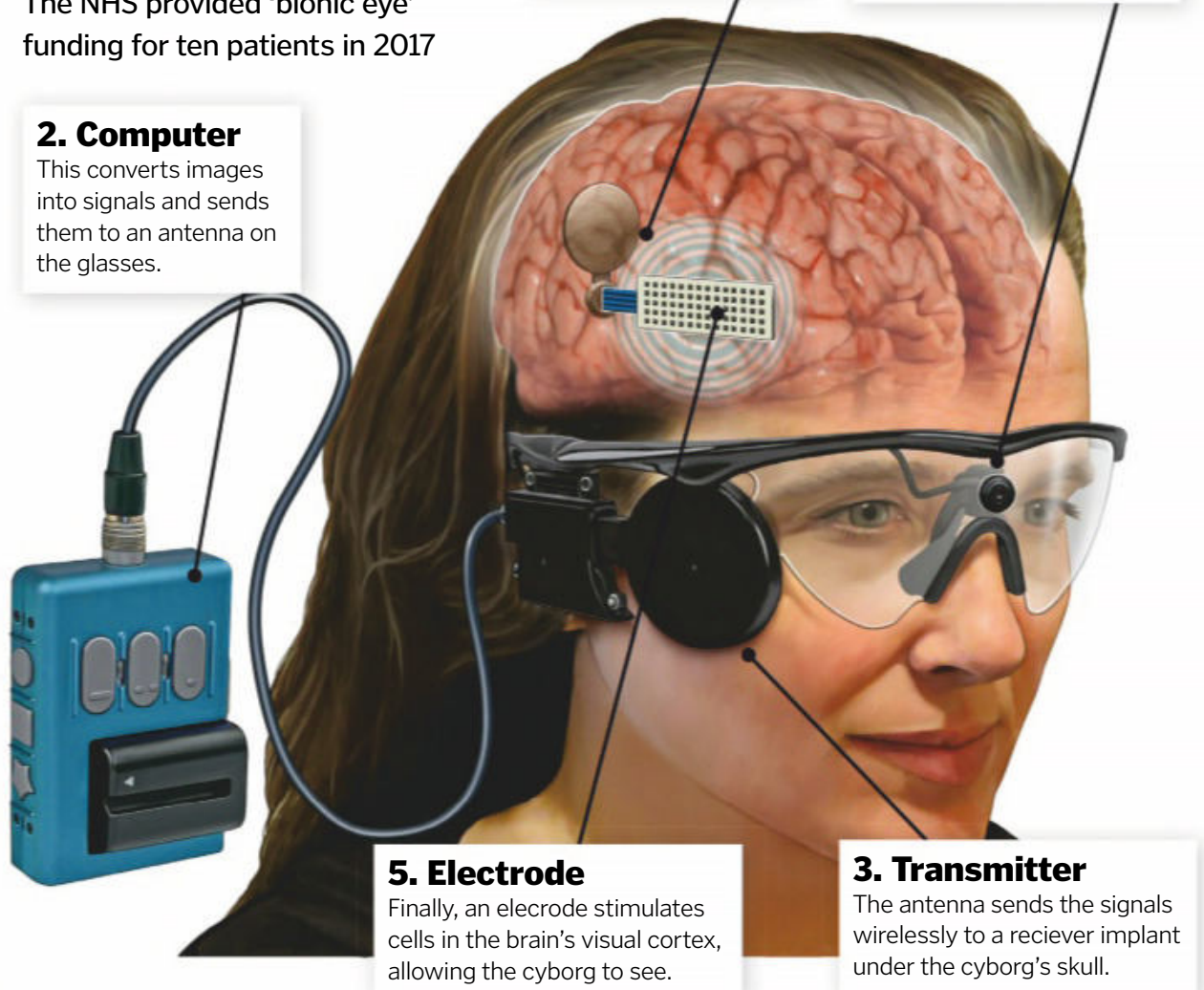
Artificial Eyes

The NHS provided 'bionic eye' funding for ten patients in 2017

4. Receiver
This picks up the signals and sends them via a wire to an electrode on the brain

1. Video Camera
A tiny camera set into the bridge captures images and sends them to a computer.

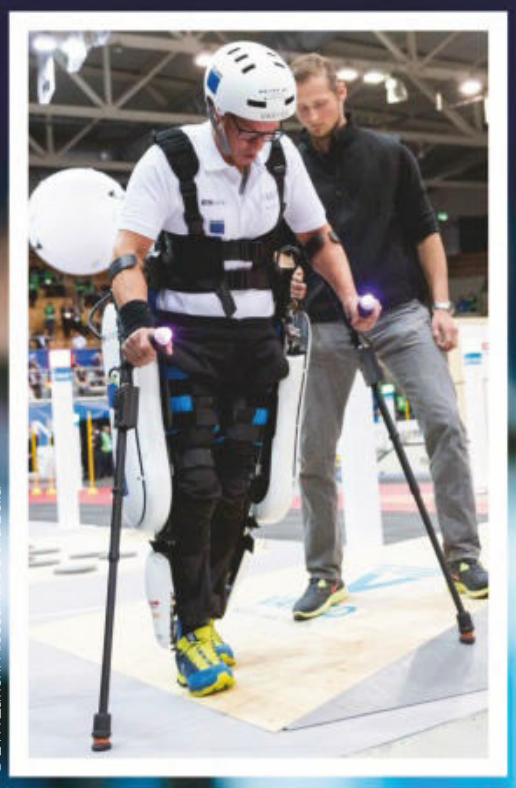
2. Computer
This converts images into signals and sends them to an antenna on the glasses.



5. Electrode
Finally, an elecrode stimulates cells in the brain's visual cortex, allowing the cyborg to see.

3. Transmitter
The antenna sends the signals wirelessly to a reciever implant under the cyborg's skull.

DID YOU KNOW? *In 2002, Jens Neumann became the first person in history to receive an electronic eye*



© ETH Zurich/Alessandro Dela Bela

Left: A paraplegic participant walks using a powered exoskeleton at the Cyborg Olympics

Screwing in a lightbulb with an artificial arm was one of the tasks at the Cyber Olympics

© ETH Zurich/Alessandro Della Bella

5 FACTS ABOUT CYBORGS AND CYBERNETICS

1 It's an old concept
The idea of a man-machine hybrid concept goes back quite a while. The 1839 short story *The Man That Was Used Up* by Edgar Allan Poe describes a man with extensive prostheses.

2 Fictional fan favourites
Cyborgs have been some of the most popular characters in film and TV history, ranging from Darth Vader and Robocop to the Terminator and the Cybermen.

3 The first-ever cyborg
The first human cyborg was created in 1997 by Dr Philip Kennedy. He successfully implanted an electrode into the brain of Vietnam veteran Johnny Ray, who was suffering from locked-in syndrome.

4 Cyborg foundation
In 2010 the Cyborg Foundation was founded to help humans become cyborgs. Moon Ribas and Neil Harbisson started the organisation after receiving numerous requests from people who wanted to be one.

5 Cyber troopers
The US military has been working on a chip that can be implanted in a soldier's brain to connect it directly to computers that can deliver data on an enemy's position, maps and battle instructions.

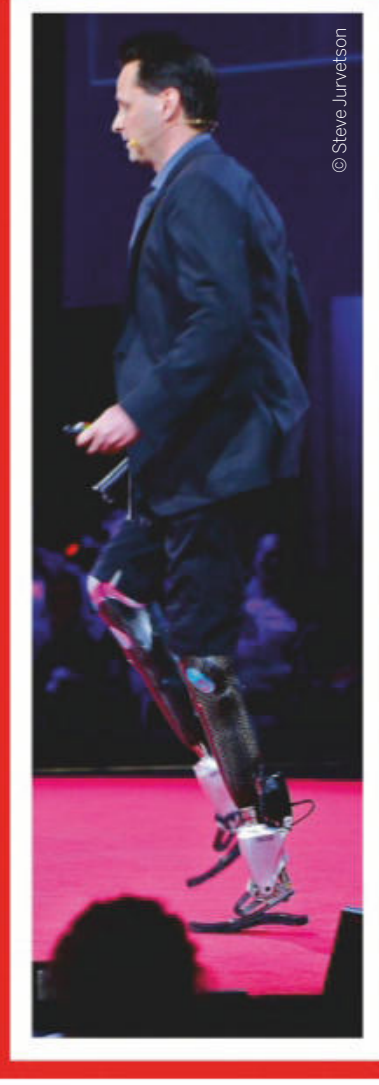
© ETH Zurich/Nicola Pitaro

Cyber Olympics participants harnessed artificial limbs to complete tasks

Could we have wings?

Imagine being able to soar high above the clouds with your very own wings, or having four arms so you can become skilled at table tennis or the drums. Bionics designer Hugh Herr at the MIT Media Lab claims the future will see 'augmented' human bodies that will change what it means to be 'human' – we could even have cybernetic wings implanted into our bodies we can control with our minds, just like we do our arms and legs, allowing us to fly.

He said: "During the twilight years of this century, I believe humans will be unrecognisable in morphology and dynamics from what we are today. "Humanity will take flight and soar."



© Steve Jurvetson

An MIT bionics expert believes humans will one day have cybernetic wings

HEROES OF... TECHNOLOGY

Martin Cooper posing with the original model of the mobile phone he invented

© Alamy

The DynaTAC was the height of innovation when it was released commercially in the 1980s

A life's work

The father of the mobile phone

1928
Marty Cooper is born on 26 December in Chicago, Illinois, to Ukrainian Jewish parents.

1950–53
Serving in the US Navy, Cooper fights in the Korean War.

1950
Cooper graduates from the Illinois Institute of Technology with a degree in electrical engineering.

1954
After a brief stint at Teletype Corporation, Cooper is headhunted by Motorola and joins the company as an engineer.

1972
As AT&T begin a project on the mobile phone, Motorola sets up a rival project and puts Cooper in charge.

He invented the cell phone

Meet Martin 'Marty' Cooper, a communications trailblazer

Sometimes invention is born out of necessity – sometimes it's born out of corporate rivalries. The latter is certainly more accurate when it comes to the invention of the mobile phone. There was so nearly a different name attached to this monumental creation, and the company its team worked for would have been AT&T. Instead, it was Marty Cooper's team at Motorola.

After getting his degree in electrical engineering from the Illinois Institute of Technology in Chicago and serving in the US Navy during the Korean War, Cooper found himself working for Teletype Corporation for a short while before moving on to Motorola in 1954. During his time there he was known as an innovator, working on projects that included the first radio-controlled traffic light system, patented in 1960, and the first handheld police radios, which were introduced in 1967. In fact, his contribution to the company was so great that he was made vice president and director of research and development in 1978. This promotion was probably in no small part due to his work earlier in the decade.

When Motorola found out that AT&T was putting a team together to invent the first mobile phone, the response was simple: the company was going to put together its own team and invent it first to avoid AT&T from dominating the market. Cooper was placed in charge, and they all got to work. Ideas were bounced around and prototypes made before, finally, they had created the Dynamic Adaptive Total Area Coverage phone, or DynaTAC. At 23 centimetres tall, it weighed 1.1 kilograms and it could be used for 35 minutes of talk time before the battery died, and it took about ten hours to fully charge. While it may not seem very impressive today, in the 1970s, that was a big deal.

Before it could be officially announced to the world that the phone had been invented, however, it needed to be tested. Cooper knew just how he was going to do so – a few days before the press conference, he stood on a street corner in New York City with the phone. He dialled a number and made the first ever call from a mobile phone. The man at the other end of the call was none other than Joel Engel, the leader of AT&T's rival project, the one that spurred Motorola into action in the first place. Now sure that it was in complete working order, Cooper unveiled the DynaTAC on 3 April 1973.

Work hadn't been finished, though – the next decade was spent refining the model, and the DynaTAC 8000x, a version suitable for consumers, went on sale in 1983. At $3,995 it wasn't exactly the most affordable piece of equipment, but it was a success nonetheless, and mobile phones have now revolutionised the world. While these early models were only good for short conversations, the technology evolved into what we know today – mobile phones can now access the internet, provide entertainment and so much more.

THE BIG IDEA

From home, to cars to becoming a truly mobile phone

Marty Cooper hadn't set out to invent the mobile phone, but he was an expert in wireless communication technology. What he and his team designed was nothing short of revolutionary. While a sort of mobile phone had existed before, attached to cars, trains and other vehicles, this would be the first that could be carried anywhere. Over the ten years between making the prototype and launching the consumer version of the DynaTAC, it was refined and the battery was improved so that talk time increased to an hour, and there was enough storage for 30 phone numbers.

© Redrum0486

The DynaTAC 8000x was released in the US in 1983 and the UK in 1985

5 THINGS TO KNOW ABOUT... MARTY COOPER

1 29 years at Motorola
Cooper worked his way up to becoming vice president and director of research and development having working on the mobile phone project.

2 Working for the competition
Before joining Motorola in the 1950s and working against AT&T to invent the mobile phone first, Cooper had actually been employed by Teletype Corporation, an arm of AT&T.

3 Prize-winning inventor
Cooper has earned many awards in his time, including the Charles Stark Draper Prize from the US National Academy of Engineering and the Marconi Prize, both in 2013.

4 Wireless communication for life
After leaving Motorola in the 1980s, Cooper founded Cellular Business Systems, Inc. and then Dyna, LLC., both of which focused on aspects of wireless communications.

5 War veteran
Cooper served in the US Navy as a submarine officer during the Korean War, but he didn't get into radio technology until he began working at Motorola, a year after the war ended.

1973
The new DynaTAC is unveiled in New York City. To check it works, Cooper phones the lead engineer on AT&T's team.

1978–83
Working his way up through the ranks, Cooper becomes vice president of research and development at Motorola.

1983
In the year the DynaTAC 8000x goes on sale, Cooper leaves Motorola and founds his own company, Cellular Business Systems, Inc.

1986
Cooper sells his company to Cincinnati Bell for $23m. He then founds another company with his wife, Arlene Harris, called Dyna, LLC.

"At 23 centimetres tall, it weighed 1.1 kilograms and it could be used for 35 minutes of talk time"

Inside the Samsung Galaxy Watch

We take a look at what makes Samsung's latest smartwatch tick

Samsung has been honing its smartwatches for the last few years. Its first effort, the Galaxy Gear, was a chunky device, didn't support enough features, and bizarrely offered a forward-facing camera that let you take photos on your wrist. It wasn't great.

Thankfully, after a few more successful iterations, Samsung is making wrist-based computers that will appeal to all kinds of users. The latest hardware, the Galaxy Watch, uses a circular display and a rotating bezel ring to make navigating around menus fast and easy. The 33mm super AMOLED display is crystal clear, and you can customise your watch with coloured straps to suit your style.

Inside the watch you'll find smart sensors that help you track your workouts, a big battery to keep you powered up for days on end, and a heart rate sensor to help you keep track of your activity throughout the day.

The standard model uses the latest Bluetooth tech to link to your smartphone, while the 4G model will even keep you connected when you venture out without your phone. You'll still be able to make calls, listen to music through wireless headphones, or get directions using your data connection. Plus, with contactless payments through Samsung Pay and simple wireless charging using the inductive charger, your wireless life will be complete.

But how does Samsung get so much tech into such a tiny device? There's only one way to find out: it's time to tear this thing down.

The stand
This charging stand makes it easy to give your Watch a battery boost – just put it on there and it will start charging.

Smart charger
This coil of wires is found inside the Watch's wireless charger, and is what powers up the battery.

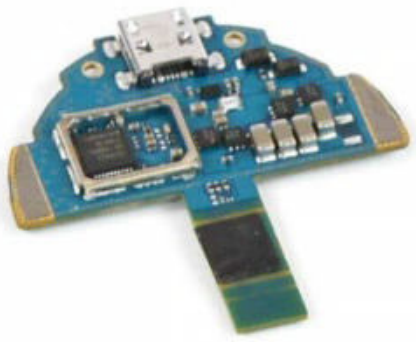
Midframe
This provides the structural integrity of the Watch. You'll also find a small vibrating motor here, which buzzes on your wrist.

Waterproofing
Rubber gaskets surrounding openings for things like the speakers and microphone keep the water out.

Main board
This is where all the work is done – the core of the computer. It's got a 1.15 GHz dual-core processor.

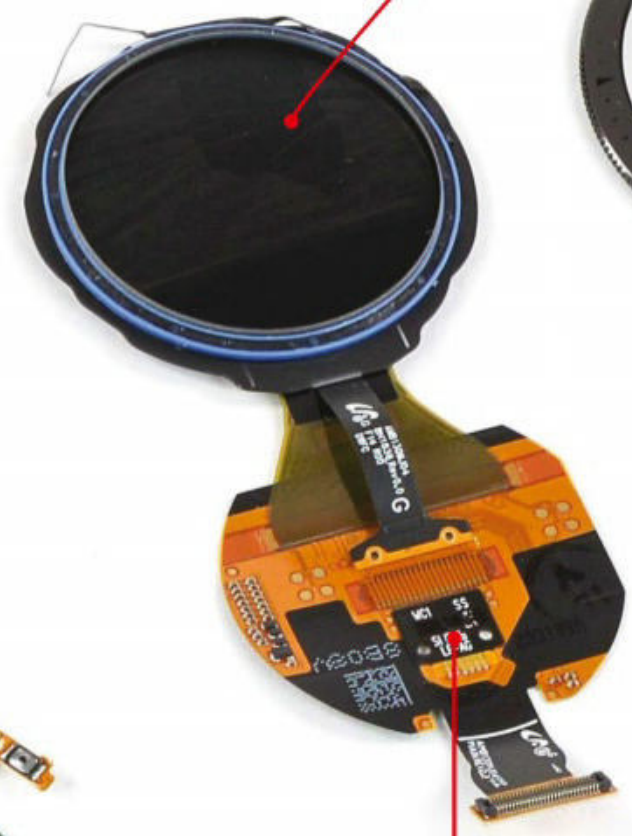
The magnets on the back of the watch, used to stick to the charging stand, hold the screws as they're removed

Battery life
This offers an impressive 1.81 Wh of power, and In the larger model this can last up to a week.

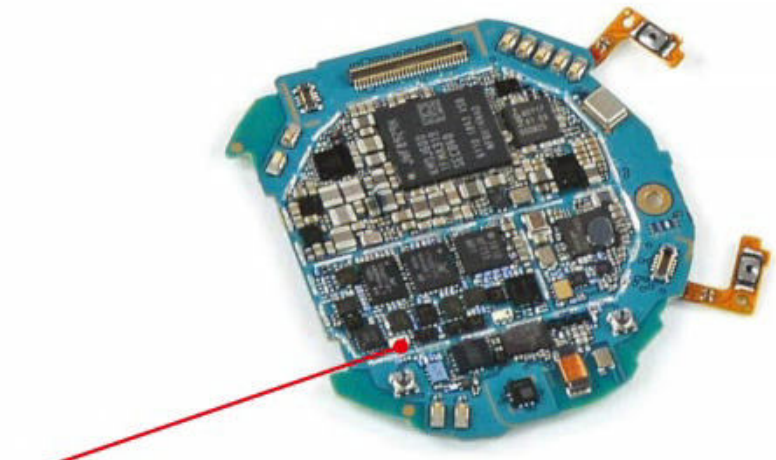


This tiny square is where the ambient light sensor pokes through display, without causing a gap in the LEDs

Sharp display
This 33mm circular Super AMOLED display is 360 x 360 pixels, making everything crystal clear.



Spinning bezel
The rotating ring on the front of the watch uses ball bearings in grooves to provide a satisfying, clicking feel.



Ambient light sensor
A small hole in the display allows the ambient light to peep through so the Watch can adjust its brightness.

"Samsung is making smartwatches that appeal to all kinds of users"

The best smartwatch competitors

Apple Watch
Apple's stylish design is backed up by hundreds of apps, a heart monitor that could (literally) save your life, and a powerful processor. It'll only work with iPhones though, so Android users will be better off with the Galaxy Watch.

Fossil Sport
Fossil's sporty offering comes packed with Google Fit for powerful workout tracking, offers GPS to track workouts without your phone, and comes with Google Assistant and contactless payment support. It's a real competitor to Samsung's Galaxy Watch, and well worth a look.

Fitbit Ionic
Fitbit was one of the first companies to embrace wearable fitness trackers, and its now using its considerable experience to create a feature-packed, fitness-focused smartwatch. The Iconic offers personalised coaching suggestions, built-in GPS, sleep tracking and music playback. It's ideal for fitness fans.

Pot distillation

How does a distillation process take gin from copper pot to cocktail glass?

The lyne arm
This delivers the vapour to the condenser column. If the arm is heated too much, water vapour may enter, diluting the end product.

Distillation chamber
Both water and ethanol vapour may enter this chamber. However, if the surrounding copper is heated correctly, only the ethanol vapour will pass through to the lyne arm.

Condenser column
Cool water is circulated around this column to condense the vapour back into a liquid state to be dispensed.

The pot
Neutral spirit, water and botanicals form a collective 'wash' in the stills pot, where it is heated until boiling.

Final product
The batch of gin is separated into three parts: the 'head' or first cut of gin is discarded, as it may contain impurities; the 'heart', which will be barreled and sold, and finally the 'tails' are also disposed of due to their imperfections.

Steam jacket
The pot and its contents are heated by a steam-filled metal jacket fed by a neighbouring boiler.

How is gin made?

Botanicals to bottle, the science behind the UK's favourite boozy beverage

The blend of herbs and botanicals are what flavour the gin

Gin has been one of the nation's favourite tipples since the early 1700s after it was introduced in London by the Dutch. The tantalising taste of this juniper-infused liquor rapidly grew in popularity and sent the residents of London into a period of gin-fuelled chaos around 1720, known as the 'gin-craze'. Part of gin's popularity was due to its accessibility and simple formula. The principle of creating basic gin is a matter of infusing the alcohol of a 'base' or neutral spirit with the aromatic flavours of juniper berries and other botanicals, such as coriander and lemon.

By distilling a combination of spirit, water and botanicals, the base is flavoured, and the final product's Alcohol by Volume (ABV) percentage is dictated. The neutral spirit arrives at a distillery at around 96 per cent ABV, and after distilling the produced gin is cut to around 40 per cent ABV. The process to achieve this, however, varies between manufacturers to create their own unique gins.

There are predominantly two methods to make this clear spirit, which can be scaled up or down for mass and domestic production. The first and more common utilises a large copper pot still whereby the neutral spirit is diluted with water and botanicals are steeped and heated for several hours. Some gin producers, however, suspend botanicals in copper baskets above the heated water and spirit wash for vapour infusion.

Once steeped, the mixture or 'wash' is then heated to produce an alcohol vapour that will travel up through connecting copper pipes. Differences in boiling points between both ethanol (around 78 degrees Celsius) and water (100 degrees Celsius), resulting in concentrated ethanol vapour escaping the wash to continue in the distillation process. Leaving the pot, this vapour flows to a condensation column, which facilitates the condensation of the vapour and is dispensed as gin.

The second method of gin distillation is similar to the first. However, rather than using a pot still for batch production, a continually filled column or 'Coffey still' is fed wash, heated before the condensed vapour is collected.

Created with copper

Notably, the prevailing material used to forge distilling apparatus for gin – and indeed a lot of other spirit distillations – is copper. This isn't an industry choice based on aesthetics, but rather copper's ability to benefit the final product's overall taste. On a molecular level, copper reacts with the bitter-tasting sulphurs that are released from fermenting yeast during alcohol production. These sulphur molecules bind to the copper walls of the distillation chambers, forming copper sulphate, which is scrubbed away once the batch distillation is complete. Copper also helps create and maintain an even temperature as an enclosure for the heated gin wash within.

As well as being a good conductor of heat, copper can improve the taste of the final gin product

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NEW MISSION TO THE MOON

How will the Chang'e 5 probe bring back pieces of the lunar surface to Earth?

Words by **Scott Dutfield**

The Chang'e 5 mission aims to reach the volcanic formation Mons Rümker

Test run

Commonly known as the Chang'e 5-T1 mission, in 2014 the CLEP launched a test mission to evaluate the likelihood of the re-entry capsule's successful journey back down to Earth. Also known as 'Xiaofei', the test-run probe was launched by the Long March 3C rocket and completed a drive-by journey to the Moon and back. Upon re-entry the capsule reached a fiery speed of 40,000 kilometres (24,855 miles) per hour. It is reported that the capsule performed a 'skip' re-entry. Similar to skipping a stone on water, the returning vessel bounced off the edge of the atmosphere in order to decrease braking distance for the delivery orbiter module.

Named after the Chinese Moon goddess, Chang'e 5 is a fifth-generation lunar probe promising to be the first Chinese return expedition. The nation's time spent investigating the Moon has surpassed a decade now, collecting vital information to better understand its origins, along with that of Earth.

It's achieved great success in observing its surface and even viewing the far side – thus far the Chinese space agency has all but brought home a piece of the Moon. However, by the end of the year, the Chinese Lunar Expedition Project (CLEP) will (hopefully) remedy this with the launch of its new Chang'e 5 lunar probe.

The over eight-ton probe aims to return samples of Moon material to Earth, a feat not achieved in the last 40 years. In order to complete its mission the unmanned lunar probe is designed in four sections: the orbital or service module, landing unit, ascender and re-entry capsule. Each of the probe's sections has been created to complete a space relay race, with each module handing off moon samples to another.

Once on the lunar surface, the relay race can begin. First, the landing unit excavates the rock samples, before feeding them into the ascender module. Taking flight, the ascender module propels itself from the surface to hand off the samples to the re-entry capsule aboard the orbiter module. In a dash across space back to Earth, the orbiter module releases the capsule, which will fire down to Earth's surface, completing the relay.

Chang'e 5's destination will be the Rümker region in the northern Oceanus Procellarum, on the Moon's near side – specifically a volcanic formation known as Mons Rümker. After the formation of the Moon, this area experienced a period of volcanism, whereby lakes of molten rock coated the surface. Regions such as Rümker were originally called mares – Latin for sea – as early observers believed them to be lunar oceans. However, it's volcanic basalt that once created the illusion of water on the Moon, and Chang'e 5's mission is to return around two kilograms of samples to Earth. With the ability to take drilled core specimens from the surface, researchers will be able to analyse the geological formation of the Moon and further our understanding of how it and Earth came to be.

The landing site is on the northwest of the Moon's near side

Lunar legacy

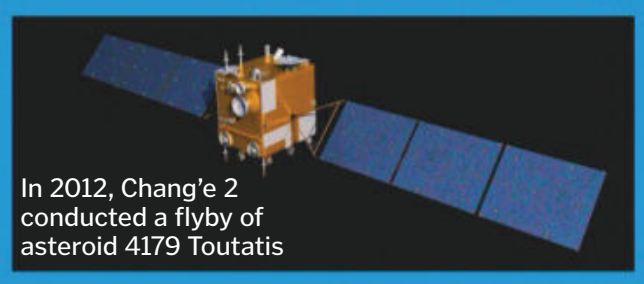
Chang'e 1

Launched in 2007, the first member of the Chang'e legacy was constructed as an orbital system to observe our lunar neighbour, collecting readings such as multispectral images, X-ray profiles and topography measurements to better understand the Moon.

Chang'e 1 circled the Moon at a distance of between 100 and 200 kilometres

Chang'e 2

The second instalment in the Chang'e probe family was launched in 2010 as a follow-up mission to the previous probe. It served as a reconnaissance mission for a potential landing site for the next generation of craft and created a high-resolution map of the Moon's surface.



In 2012, Chang'e 2 conducted a flyby of asteroid 4179 Toutatis

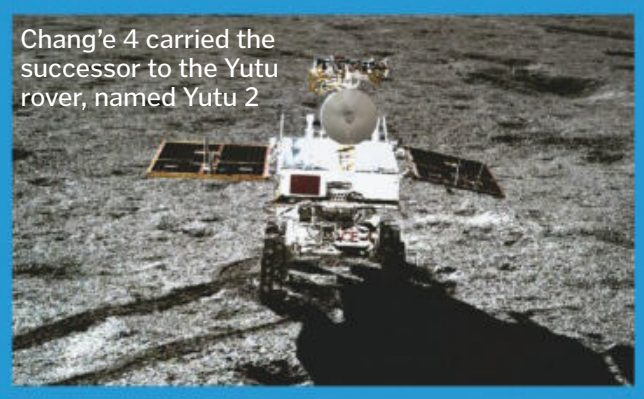
Chang'e 3

Achieving the first soft landing on the Moon in some 40 years, the Chang'e 3 Yutu rover made history after its launch in 2013. Landing in Mare Imbrium, the six-wheeled rover scoured the surface taking high-resolution images before a mechanical failure rendered it obsolete in 2016.

The Yutu rover's mission lasted 31 months, roughly ten-times longer than planned

Chang'e 4

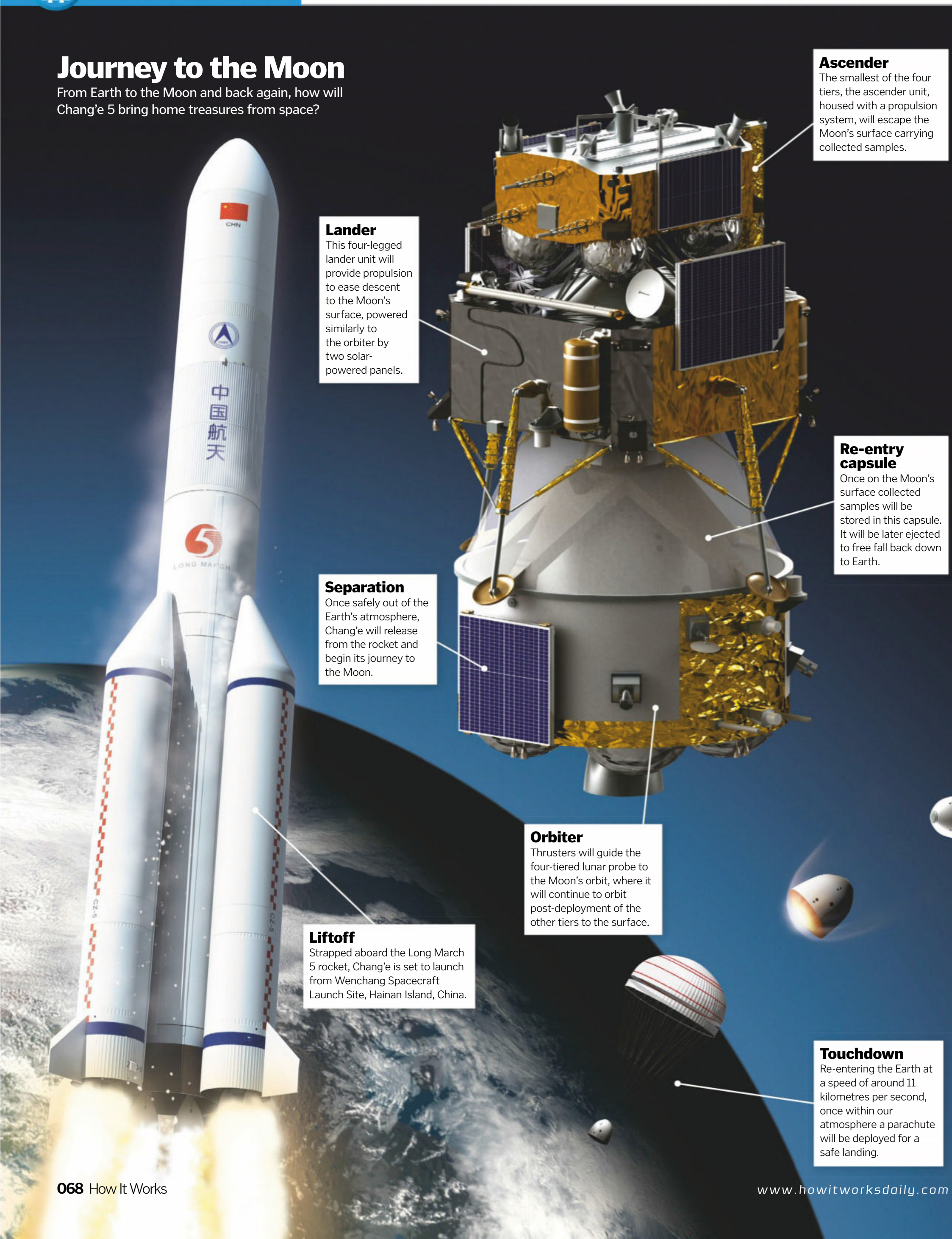
Arriving on the far side of the Moon earlier this year, the predecessor to Chang'e 5 made history for the CNSA by becoming the first spacecraft to land on the space-facing side of the Moon. This momentous achievement was aided by the successful orbit of the Queqiao relay satellite, which allowed communication between ground control and Chang'e 4.



Chang'e 4 carried the successor to the Yutu rover, named Yutu 2

Journey to the Moon

From Earth to the Moon and back again, how will Chang'e 5 bring home treasures from space?



Ascender
The smallest of the four tiers, the ascender unit, housed with a propulsion system, will escape the Moon's surface carrying collected samples.

Lander
This four-legged lander unit will provide propulsion to ease descent to the Moon's surface, powered similarly to the orbiter by two solar-powered panels.

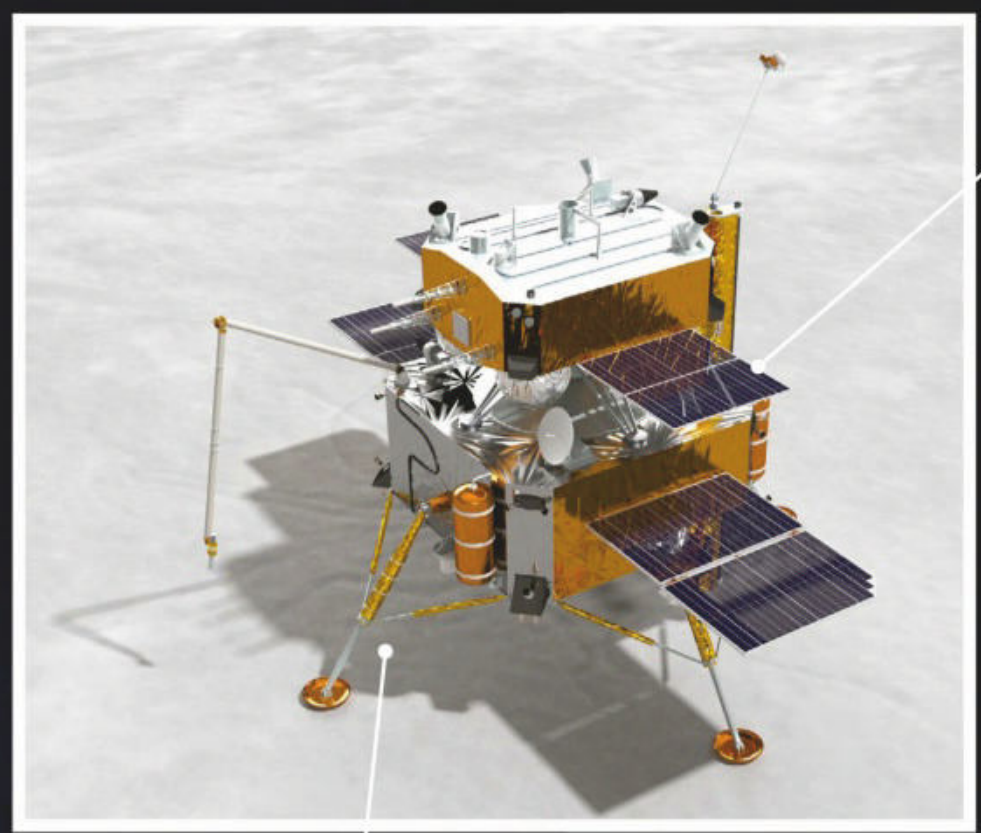
Re-entry capsule
Once on the Moon's surface collected samples will be stored in this capsule. It will be later ejected to free fall back down to Earth.

Separation
Once safely out of the Earth's atmosphere, Chang'e will release from the rocket and begin its journey to the Moon.

Orbiter
Thrusters will guide the four-tiered lunar probe to the Moon's orbit, where it will continue to orbit post-deployment of the other tiers to the surface.

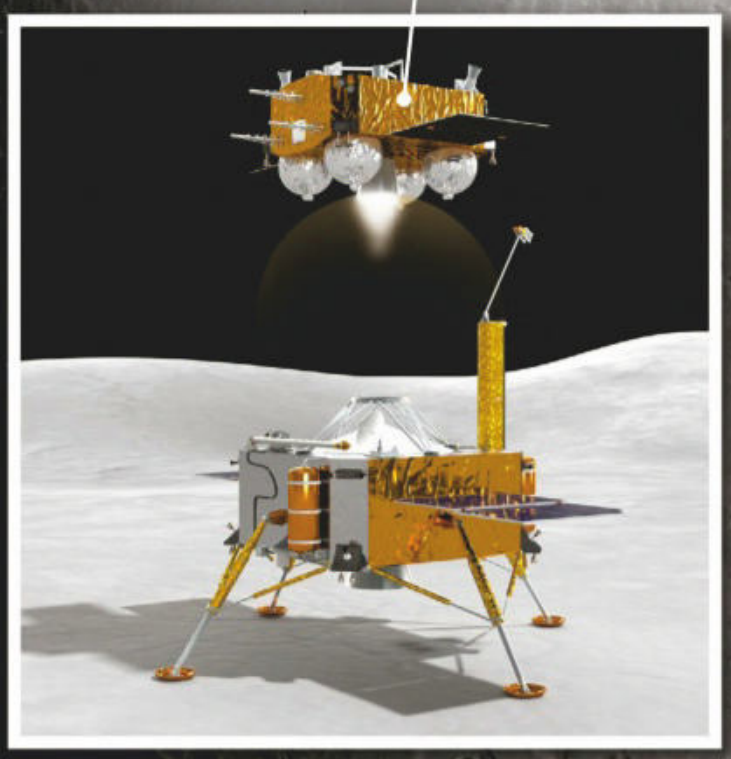
Liftoff
Strapped aboard the Long March 5 rocket, Chang'e is set to launch from Wenchang Spacecraft Launch Site, Hainan Island, China.

Touchdown
Re-entering the Earth at a speed of around 11 kilometres per second, once within our atmosphere a parachute will be deployed for a safe landing.

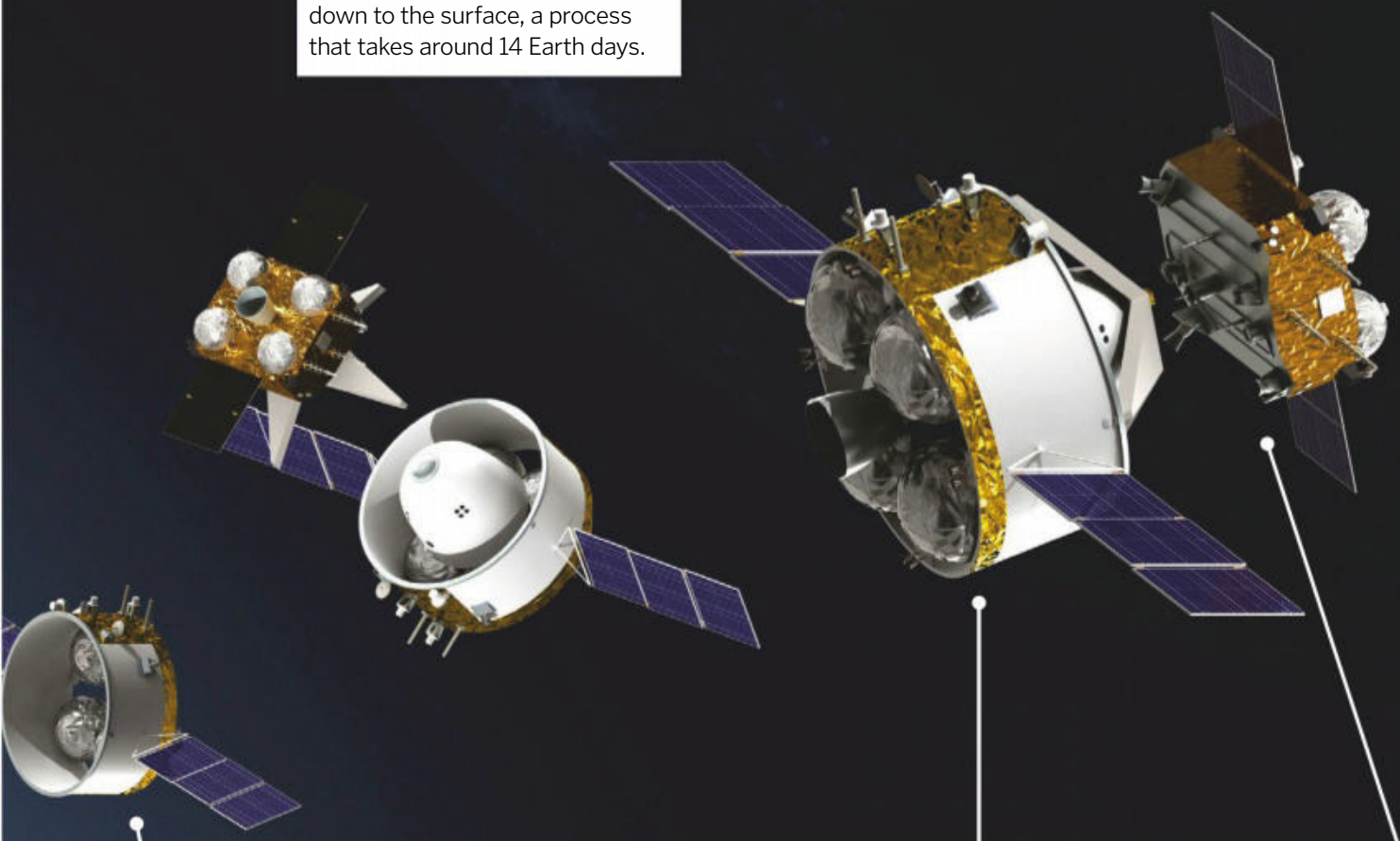


Sample collection
Once safely on the surface the landing module will collect core samples, possibly from as deep as two metres.

Takeoff
Samples packed, the ascender module propulsion system will ignite and separate from the landing unit, rejoining the orbiter module still in the Moon's orbit.



Landing
Separated from the orbiter, the remaining tiers will be lowered down to the surface, a process that takes around 14 Earth days.



Delivery
Reaching around 5,000 kilometres from Earth's surface, the orbiter will jettison the re-entry capsule and it will fall through the Earth's atmosphere.

Homeward bound
With the lunar loot aboard the orbiter, the pair will propel back towards Earth, a journey that will take roughly five days.

Docking
While in lunar orbit the ascender will transfer the samples to the re-entry capsule housed in the orbiter module before disconnecting.

Lunar orbit
The orbiter, also known as the service module, will propel Chang'e 5 to the Moon's orbit, reaching around 200 kilometres from its surface.

10 WAYS TO SURVIVE IN SPACE

In the latest *Avengers* film, Tony Stark is adrift in his spacecraft. What could he do to increase his chances of surviving until rescue?

URGENCY LEVEL

High

Medium

Low

Maintain oxygen supply

It takes just 15 seconds for your body to use all its oxygen when exposed to a vacuum. A process known as electrolysis, used on the International Space Station (ISS), passes electricity through water to separate the oxygen and hydrogen molecules for breathable air. Assuming your drifting shuttle is equipped with solar panels for power, electrolysis can keep you breathing. Just be sure to vent the highly flammable hydrogen back into space.

Stay pressurised

Our bodies are continually held under atmospheric pressure on Earth. However, in space, no such pressure exists. Without it, blood and body fluids change state and effectively 'boil' then freeze in around 30 seconds. In order to prevent turning into frozen space soup, spacecraft and spacesuits are pumped with oxygen to maintain pressure.

Block out radiation

Interstellar travel requires protection from harmful rays that we're protected from on Earth by the atmosphere. Dense metals and reflective panels are used for the exterior of a spacecraft, typically to offer protection. Studies have shown that filling bags of water, liquid or solid human waste can create a radiation barrier known as a 'water wall'.

Combat changing temperatures

Temperatures fall and rise to the extremes in open space. On the Sun-facing side of the ISS it can reach up to 121 degrees Celsius, while the opposite side plunges to around -157 degrees Celsius. Multi-layered insulations and a network of pipes carrying heated ammonia keep the internal environment at a constant temperature. During a deep-space drift, reflective materials may be your best friend – by blocking the Sun's warming ultraviolet radiation, for example.

Ration your food

The human body has been recorded to last up to 21 days without food. However, finding a meal in space is impossible, unless you bring a bite with you. Currently, astronauts take dehydrated meal packets that they rehydrate and heat on the ISS. Current studies exploring the possibility of growing plants in microgravity via hydroponics – using a nutrient solution instead of soil – and aeroponics – the use of a nutrient-filled mist – are also proving successful. But if you find yourself landing on a barren planet, you could also attempt to grow potatoes, Matt Damon style.

Call for help

Finding yourself lost in space, there is hope that Earthbound communication centres such as NASA would be on the hunt to pinpoint your location via the satellite relay system orbiting the planet. Depending on how far your shuttle has drifted, anywhere between Earth and Mars, telemetry can be picked up by satellite, though clear audio may be not functional. Going back to basics and sending bursts of radio signals in Morse code may be the best bet for sending an SOS.

Take your vitamins

During a six-month mission on the ISS, astronauts will be exposed to around 160 mSv of radiation, 1,600-times that of a single chest X-ray. Prolonged exposure to radiation can lead to mutation in the body's DNA structure, leading to an array of health problems. Taking antioxidants like vitamins C and A can absorb some radiation-produced free radicals to limit their effects on the body. Similarly, pectin in fruit and vegetables can combat the long-term effects of exposure.

Start filtering

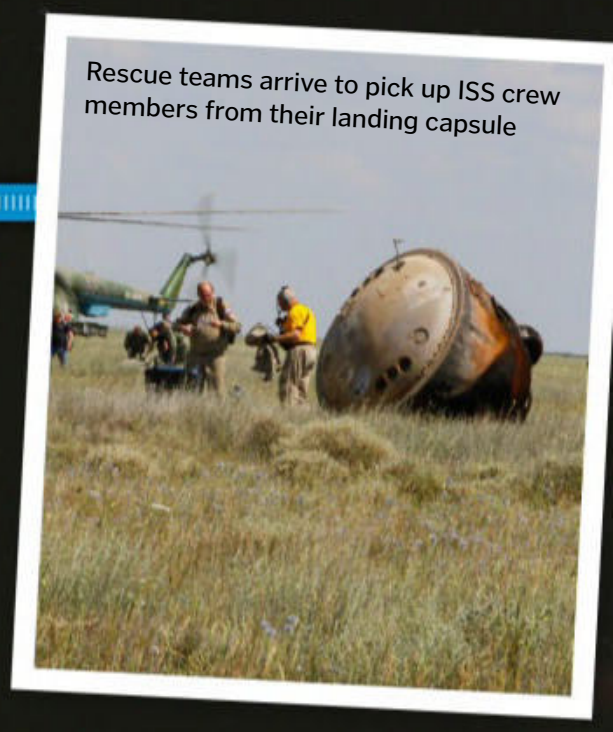
One of the most vital demands of the body, regardless of whether you're on the Earth or out in space, is water. When it comes to water when lost in space, recycling is the best way to stay hydrated. The ISS recycles nearly every drop of water produced within its walls – around 93 per cent. From fuel cells to urine and even the humidity in the air, water is pumped through a series of filters and distillers to produce pure drinking water.

Keep active

Prolonged time in microgravity can take its toll on your body. Due to the lack of gravity forcing muscles to fight against its pull, the function of the muscles, particularly in the legs, becomes redundant, resulting in atrophy. After 180 days in space muscular strength can decrease between 11 and 17 per cent, and bone mineral density can reduce by between two and seven per cent.

Stay stimulated

Once the critical conditions of survival in space have been met and you've managed to secure clean air, water and radioactive protection, it's time to sit back and wait for rescue. However, continually staring out into the vast expanse of space is enough to send even the strongest-minded individuals into madness. Keeping your mind occupied becomes vital.



Rescue teams arrive to pick up ISS crew members from their landing capsule

Betelgeuse burns brightly at the top of Orion

What's the next star to explode?

Red giant Betelgeuse is gearing up for a huge supernova

Look up on a clear night and you might be able to spot the constellation of Orion, the Hunter. Marking the shoulder of Orion's raised arm is Alpha Orionis, or Betelgeuse. This star, around 640 light years from Earth, is the second-brightest in the constellation – after Rigel, one of Orion's feet – and one of the brightest stars in the sky.

Betelgeuse is a red supergiant, distinctly orange when viewed through a telescope. Being so large and burning so bright means this giant has a relatively short life expectancy. Smaller stars can live for billions of years, but Betelgeuse, at just 8 million years old, is already showing the symptoms of old age. Bubbles on the surface and a plume almost the size of our Solar System are signs that it's rapidly losing dust and gas, and astronomers have observed rapid fluctuations in the star's size and shape.

Betelgeuse is running out of fuel and creating increasingly heavy elements at its core. It's likely that the core will eventually reach a critical mass, and the red giant will implode under its own gravity. The implosion of a dying star forces atoms in the core closer together until they suddenly repel each other, like a spring releasing, and the material that once formed the outer layers of the star is flung out into space at up to 40,000 kilometres per second in a magnificent supernova.

Betelgeuse's supernova is considered 'imminent', but that's on a cosmological time scale; astronomers estimate it could explode any time up to a million years from now.

Betelgeuse in numbers

200

There are very few red supergiant stars identified in the Milky Way

3,315°C

Although it's brighter, Betelgeuse is much cooler than the Sun

'Betelgeuse' is a poor translation of the Arabic for 'shoulder of the giant'

100,000

Betelgeuse has a luminosity around 100,000-times greater than our Sun's

In Tahitian lore, Betelgeuse is one of the pillars that holds up the sky

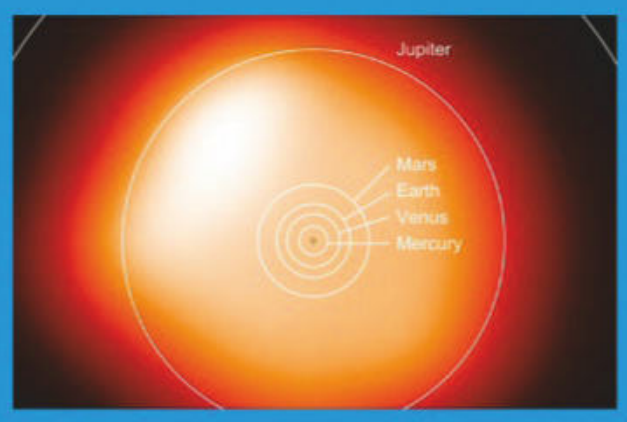
100,000 years

Some astronomers believe Betelgeuse will explode much sooner than others predict

The shrinking supergiant

Betelgeuse is classified as a red supergiant. The star is estimated to be up to 1,400-times the size of the Sun. Relatively little is known about what exactly happens towards the end of a red giant's life, and Betelgeuse is puzzling astronomers with its unusual activity. Not only is it rotating around 150-times faster than expected for a star of its size and expelling gas at a lower temperature than scientists would have predicted, it also appears to be shrinking.

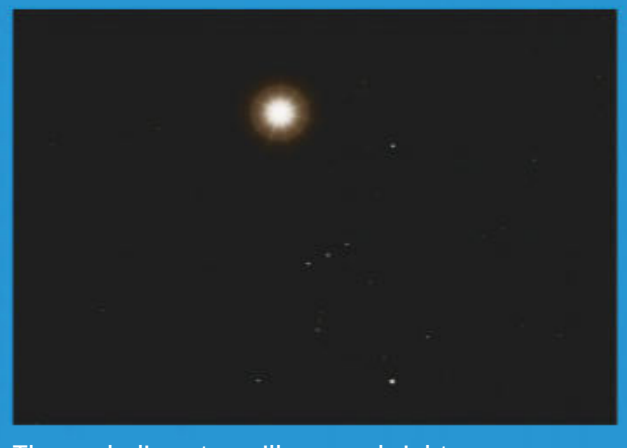
Observations from several telescopes show that Betelgeuse's radius dropped by 15 per cent between 1993 and 2008. Dying stars usually swell and expand before collapsing, so scientists are monitoring this giant to see whether it continues to contract or begins to increase in size.



At the centre of the Solar System, Betelgeuse would engulf Jupiter and all the terrestrial planets

Betelgeuse's big finale

If there are still humans on Earth when Betelgeuse finally explodes as a supernova, they won't be able to miss the star's dramatic exit from the cosmos. Alpha Orionis is already more brilliant than most stars, but when it explodes it will appear as bright as the full Moon for weeks or even months. Betelgeuse is too far from us for the heat, radiation and matter thrown out in its explosion to pose a threat, so any people around to witness it will be able to enjoy the breathtaking sight without worrying about Earth being melted or hit by a shockwave.



The exploding star will appear bright even during the day

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The Age of Steam

Discover how simple water vapour revolutionised transportation and global industry

Words by **Charles Ginger**

Prior to the Age of Steam and the Industrial Revolution it fuelled, the world was a pretty slow place. Until the turn of the 17th century, humanity had been forced to rely on the whims of Mother Nature and the raw strength of animals in order to travel and transport goods. Had it not been for the minds of men such as Thomas Newcomen, Denis Papin and Thomas Savery, little would have changed.

An explosion of steam-powered devices that began in earnest with Newcomen's creation of the atmospheric engine in 1712 soon saw this game-changing technology above the surface of mines and on factory floors, enabling the creation of faster, more efficient machinery. Suddenly, goods like coal and food could be transported over vast distances at greater speeds, cutting down on costs and waiting times.

People too could now explore the lands beyond their towns and cities, a development that unleashed a wave of trade and migration. A time of endless possibilities dawned, and it was only the beginning.

Steam-powered car

In 1770, French Army captain Nicolas-Joseph Cugnot built a full-sized fardier à vapeur (steam dray) that relied on steam power to move. Yet despite being the first vehicle capable of manoeuvring independently, Cugnot's invention had its drawbacks, including the need to stop every 15 minutes to relay the fire that generated the steam fuelling it, and a top speed of just four kilometres per hour.

The ungainly steam dray still broke new ground in the quest to improve transport

Steam locomotives completely transformed the way in which both goods and people could be transported

Mineshaft super-suction

An ironmonger by trade, Thomas Newcomen was also a Baptist preacher in the churches of Devon, but it wasn't his skill with metal – nor his strength of faith – that secured his place in the history books. Instead it was his groundbreaking invention of the atmospheric engine.

Utilising principles drawn up by Thomas Savery and Denis Papen, Newcomen built a steam engine that could be used to drain water from mines. It relied on creating a vacuum within a cylinder located above boiling water. This would in turn pull down on a piston inside the cylinder, thereby manoeuvring a beam engine (a wooden beam situated on a central pillar). As the beam moved up and down it in turn pulled on a chain attached to it that ran down a mineshaft to a pump. This clever mechanism drew the water out of the mine and up into the cylinder pump before expelling it.

While it would be improved on numerous occasions later, Newcomen's engine paved the way for the harnessing of steam power

Power slammer

How did the steam hammer shape the work of metal factories in the 1800s?

The SS Great Eastern was the world's largest ship when it set sail in 1858

Steam cylinder

Steam injected into the cylinder raised the hammer in preparation for a downward stroke, which would begin once the pressure was released and gravity drew the hammer down.

Piston rod

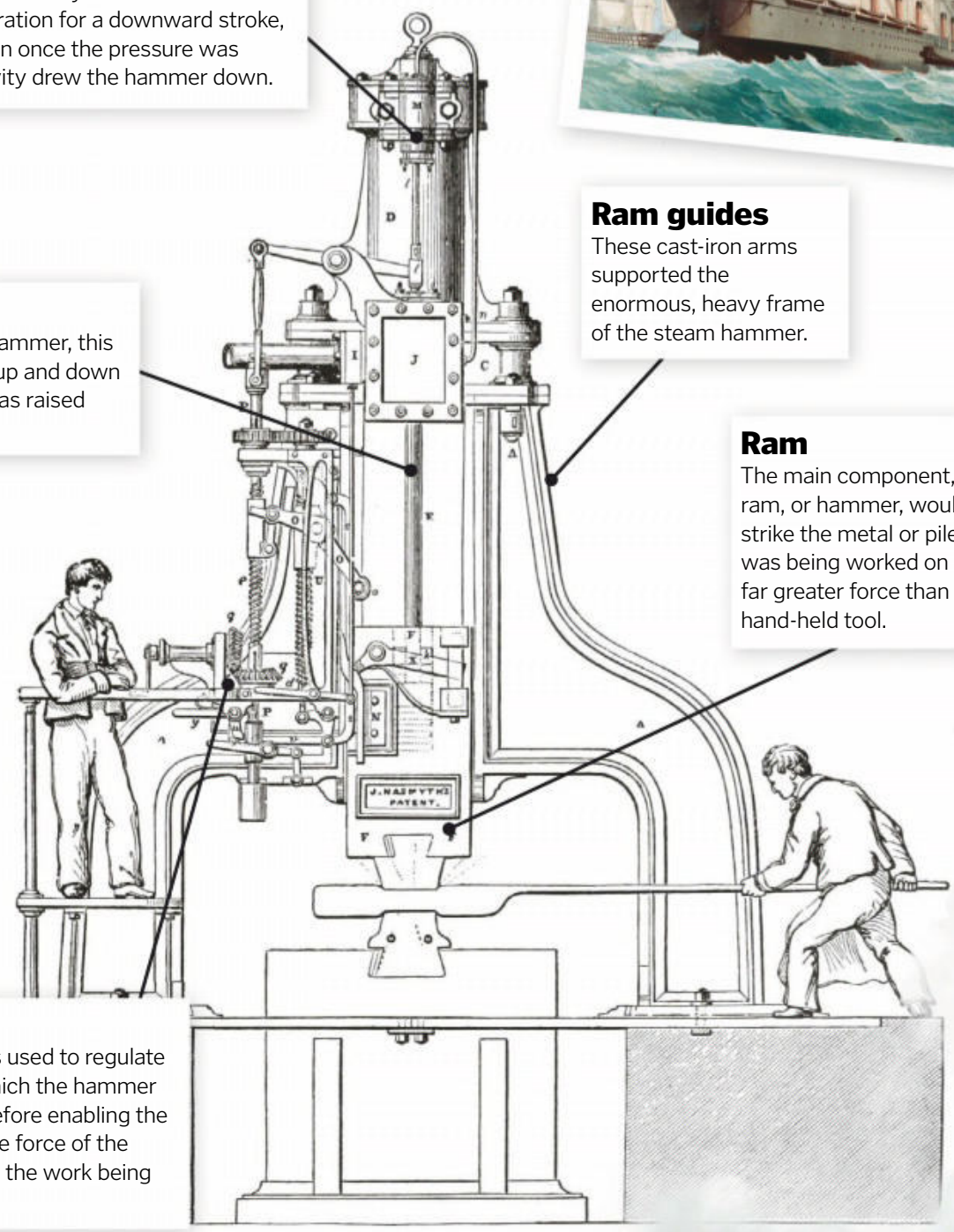
Attached to the hammer, this moved vertically up and down as the hammer was raised and dropped.

Ram guides

These cast-iron arms supported the enormous, heavy frame of the steam hammer.

Ram

The main component, the ram, or hammer, would strike the metal or pile that was being worked on with far greater force than a hand-held tool.

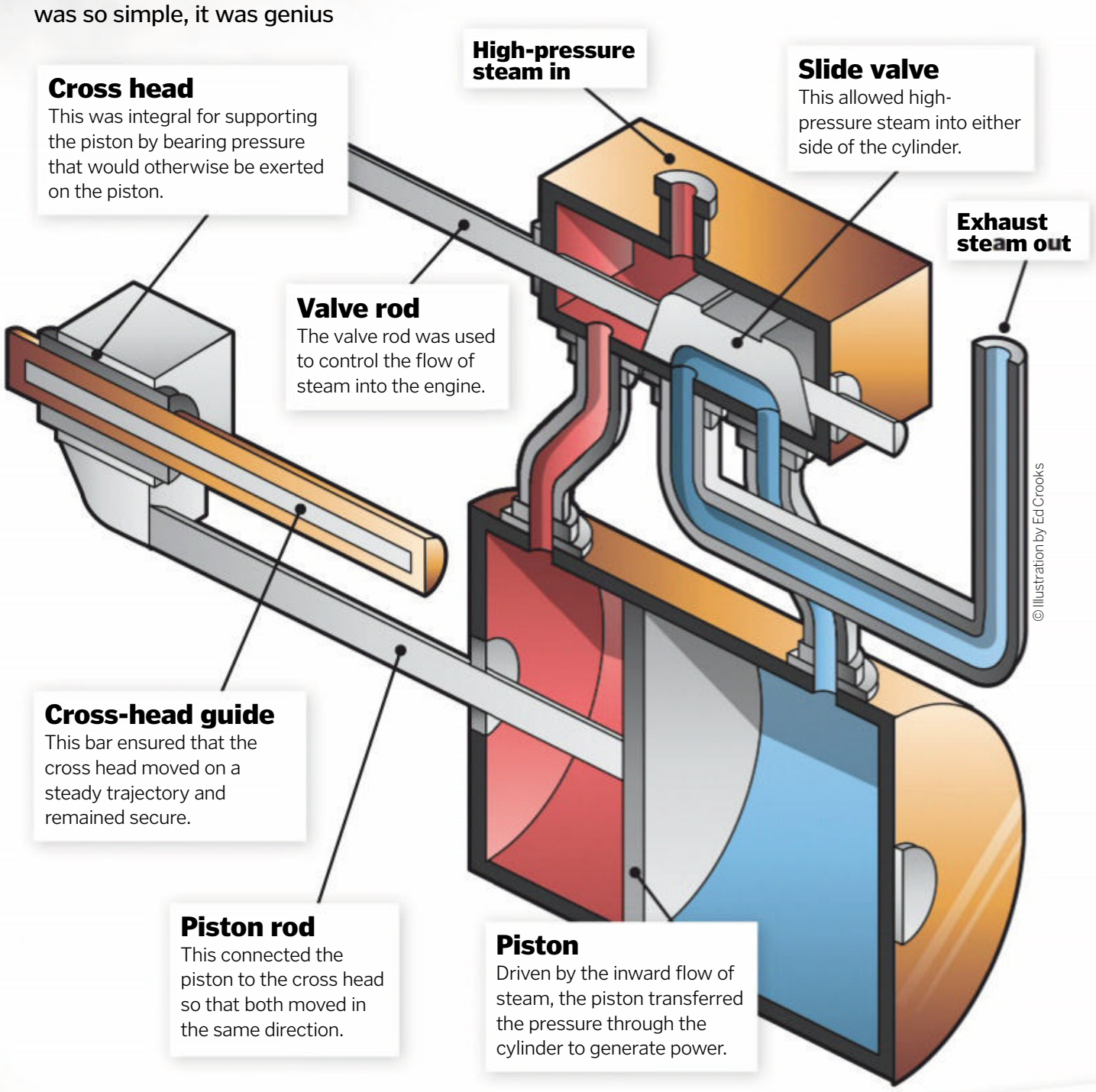


Valve gear

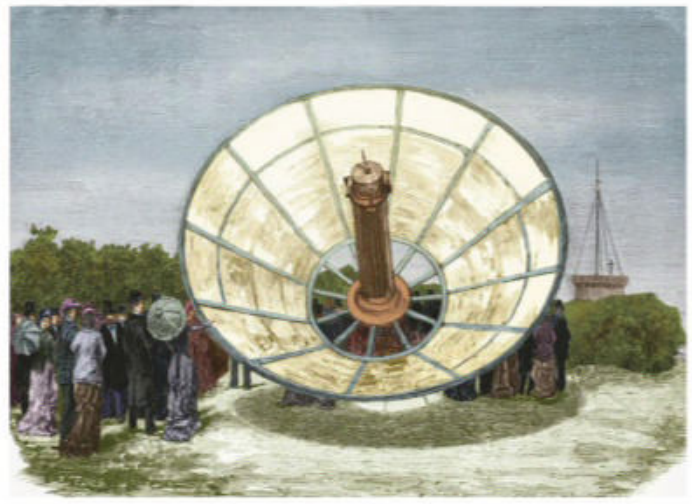
The valve gear was used to regulate the height from which the hammer was dropped, therefore enabling the operator to alter the force of the blow depending on the work being carried out.

Inner workings of a steam engine

The invention that sparked the age of steam was so simple, it was genius



Mouchot's genius being demonstrated before a captive audience at the Universal Exhibition of 1878



Solar steam engine

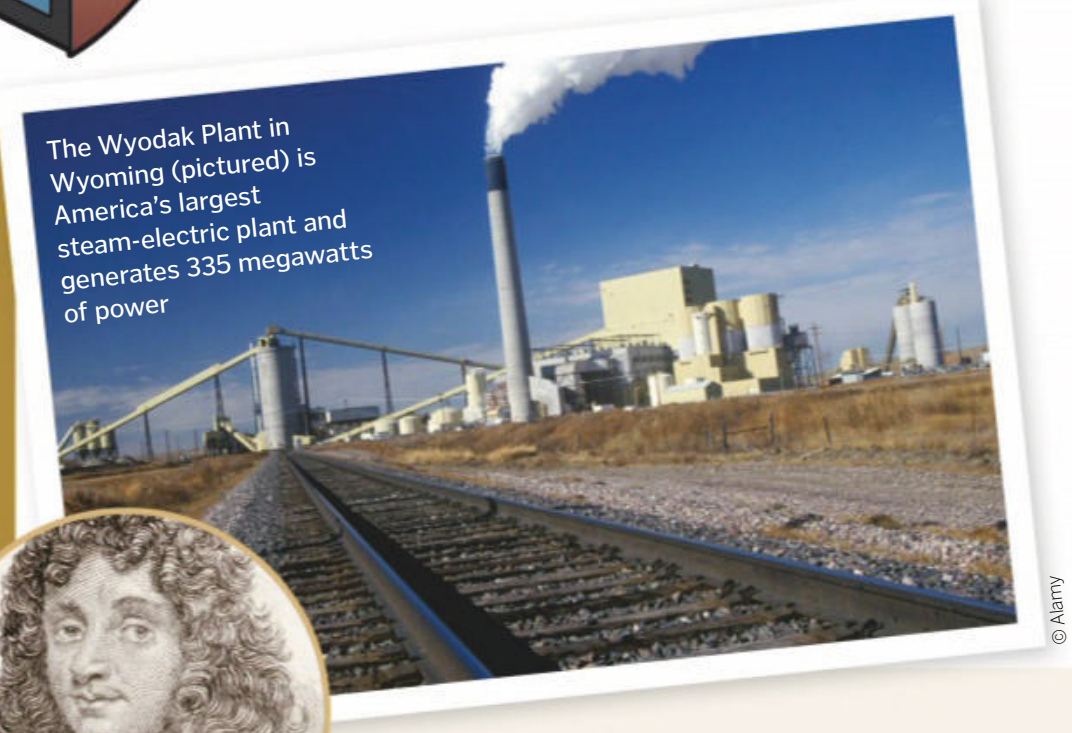
It remains one of the greatest technological injustices that Augustin Mouchot's genius was never appreciated during his lifetime. Born south of Paris in April 1825, Mouchot was a visionary who recognised that the oil and coal the industrialised world was consuming couldn't last forever. Realising the potential of solar power, he dedicated six years of work to constructing the first parabolic solar collector.

This simple yet efficient mechanism comprised an array of mirrors reflecting sunlight onto a water-filled metal tube. The steam generated by the heating of the water was then funnelled into driving a steam engine. Despite displaying his brilliance at the Universal Exhibition in Paris in 1878, a dramatic fall in the cost of coal would see fledgling support for his idea fade, leaving the pioneering Mouchot to live out his final years in destitution. The world has

Apparently, the aeolipile could predict weather

Weather forecaster

Created by Heron of Alexandria in the 1st century CE, the aeolipile may only have been a curiosity, but it was without doubt an important predecessor to the future steam-powered technology that would change the world. Comprising an empty sphere positioned above a cauldron of boiling water, hollow tubes fed steam into the sphere in order to cause it to rotate.



The Wyodak Plant in Wyoming (pictured) is America's largest steam-electric plant and generates 335 megawatts of power

Steaming ahead

1st century CE
Heron of Alexandria invents the aeolipile.

1125
Steam-powered organ described in Reims, France.

1206
Ismail al-Jazari invents an early crankshaft.

1551
Ottoman polymath Taqi al-Asadi describes a steam-driven spit.

1601
Italy's Giambattista della Porta uses steam to push water through a fountain.

1663
Edward Somerset publishes his workings on a steam pump.

1680
Christiaan Huygens makes the first known mention of a piston engine.

1698
Thomas Savery constructs the Miner's Friend steam pump.

1712
Thomas Newcomen produces his atmospheric engine.

"Carts and sailing boats were replaced with steam-powered locomotives and ships"

All aboard!

How coal, water and steam drove the trains of the industrial age

Throttle
This controlled a series of valves that opened sequentially to regulate the flow of steam, and to stop and start the train.

Steam dome
Steam produced in the boiler was collected in the steam dome.

Dry pipe
This transported the steam from the dome to the superheater.

Valve gear
This gear controlled the inlet and exhaust valves in order to let steam into the cylinder and eject exhaust steam at the right times.

Smokebox
Once steam was used in the cylinders, it was forced up into the smokebox via a blast pipe, creating a draft that fed the fire as it was exhausted through the stack (chimney).

Firebox
Coal was shovelled into the firebox to burn and heat water to generate steam.

Boiler
Metal water tubes ran through the boiler and were heated by the fire to produce steam.

Piston
Steam was funnelled to the piston, which was attached to connecting rods that linked it to the driving wheels.

Al-Jazari's crankshaft

Living in what is today Turkey during the 6th century, Ismail al-Jazari has been credited with dreaming up numerous pioneering inventions, among which was an early version of the crankshaft. Featured in a two-pump system, it worked by using a wheel to manoeuvre crankpins back and forth, thereby turning rotary into linear motion – a fundamental component of the future steam engine.

1770
French inventor Cugnot builds the first full-sized steam dray.

1776
First commercial Boulton & Watt engine built.

1804
First ever steam locomotive, made by Richard Trevithick, is operated.

1807
Robert Fulton's Clermont becomes the world's first passenger steamboat.

1825
Stockton and Darlington Railway, the first public company to use steam locomotives, opens.

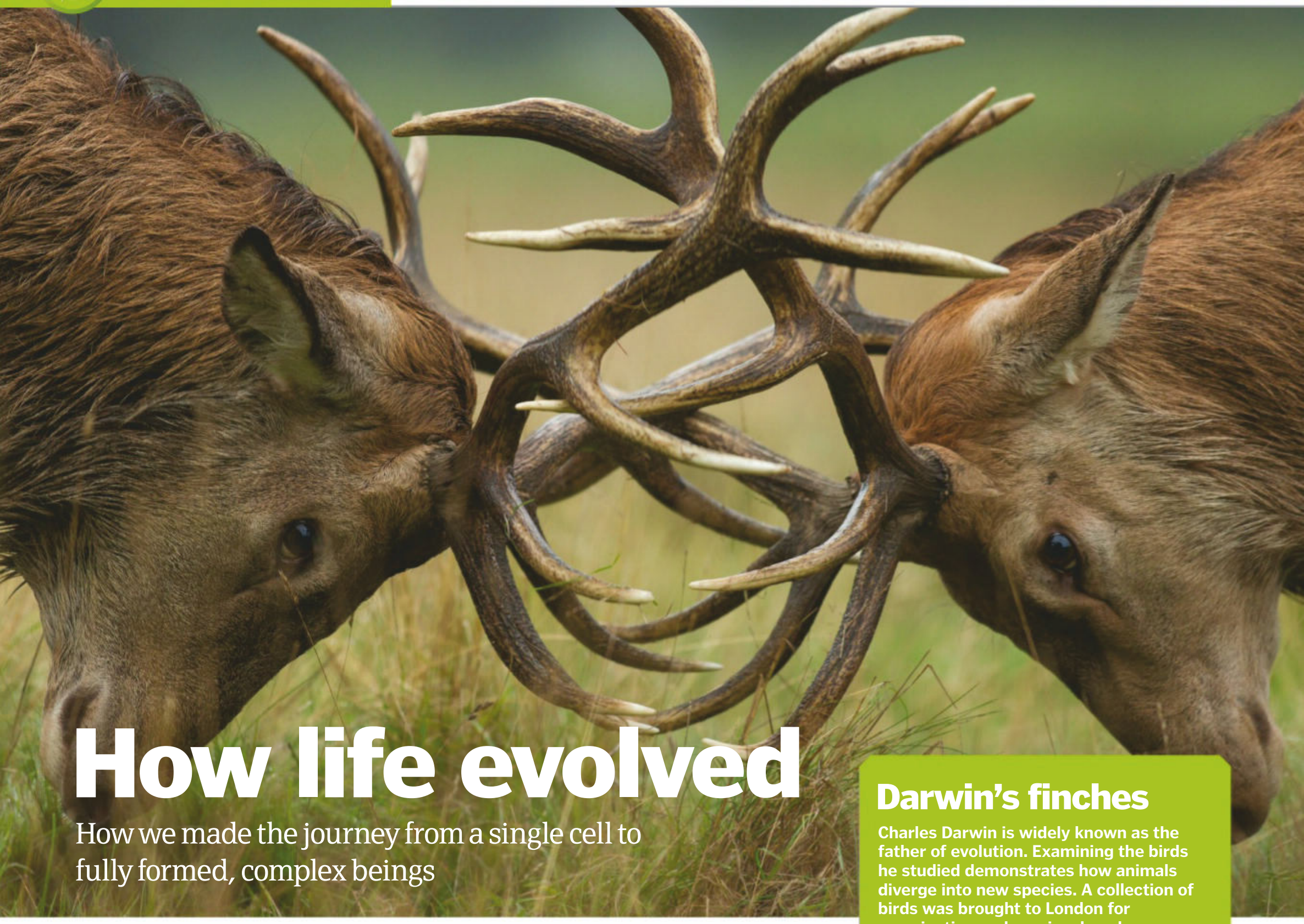
1838
SS Great Western, the first transatlantic steamship, completes its maiden voyage.

1903
Largest turbine generators in the world begin operation in Chicago.

1913
Nikola Tesla patents a bladeless steam turbine.

1933
George and William Besler become the only aviators in history to fly using steam.

2009
New speed steam record of 225.055kph set.



How life evolved

How we made the journey from a single cell to fully formed, complex beings

Our planet has existed for around 4.5 billion years. 3.8 billion years ago life emerged on Earth. The first life forms probably developed in deep sea hydrothermal vents. These hot alkaline springs react with bedrock from beneath the surface and burst through, spouting elements from the depths like boron and potassium. This mineral-rich spew mixing with the seawater brought on an array of chemical reactions. Organic molecules were produced, followed by molecules that were capable of replicating themselves. Complete cells developed, and eventually organisms made up of different types of cell.

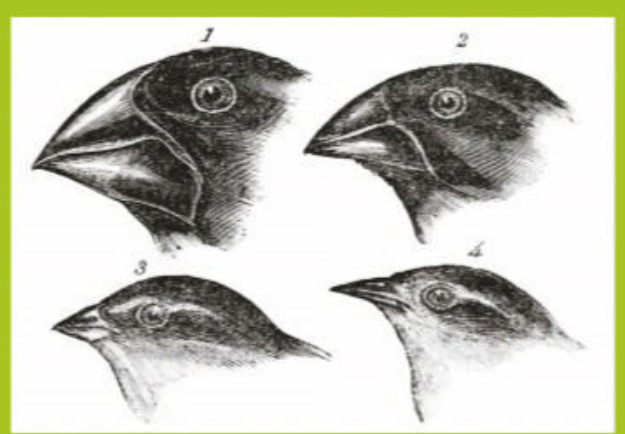
There's some speculation about what the very first animal to evolve was. Scientists thought sponges came first for a long time, but new evidence points to the comb jellyfish as the original animal. It's certain that all life was constrained to the sea for at least 600 million years. The ozone layer was yet to form and the land was exposed to deadly levels of ultraviolet radiation. In this vast expanse of time replicating DNA went through mutations that caused it to develop new forms of cell. Useful mutations were passed down to the next generation and harmful ones prevented animals from living long enough to reproduce. Advantageous genes were selected by nature, allowing animals to change over time.

Animals didn't venture on to land until they had a reason. Moss-like plants had begun to grow, and by 530 million years ago primitive arthropods were feeding on them. A million years later the fish of the sea were transforming into amphibians. They relied on water to reproduce, but could feed on land. Amphibian spawn must be laid in water, as their larval forms are aquatic. Around 300 million years ago reptiles emerged with a portable baby carrier we call an egg, thus answering the age-old question of which came first. The amniotic egg let animals venture away from the sea permanently and adapt to their new surroundings. Reptiles ruled the earth until 65 million years before today. Mammals then quickly took control, beginning with rat-like animals that became ancestors of modern primates, like humans.

Darwin's finches

Charles Darwin is widely known as the father of evolution. Examining the birds he studied demonstrates how animals diverge into new species. A collection of birds was brought to London for examination and previously unknown species were classified. A group of 13 new finch species caught Darwin's eye. He realised the birds had diversified into different forms from a common ancestor.

Darwin's birds were spread out across six islands. Populations became isolated from one another and bred within their own flock. Each finch specialised to feed on different food sources and passed on their genetic material. Warbler finches developed slender beaks to pick out tiny insects. Ground finches sought out crunchy seeds and arthropods, and have the thickest bill of any Galapagos finch.



The beaks of ground finches (above) compared to the bills of the small tree finch and warbler finch

Back into the ocean

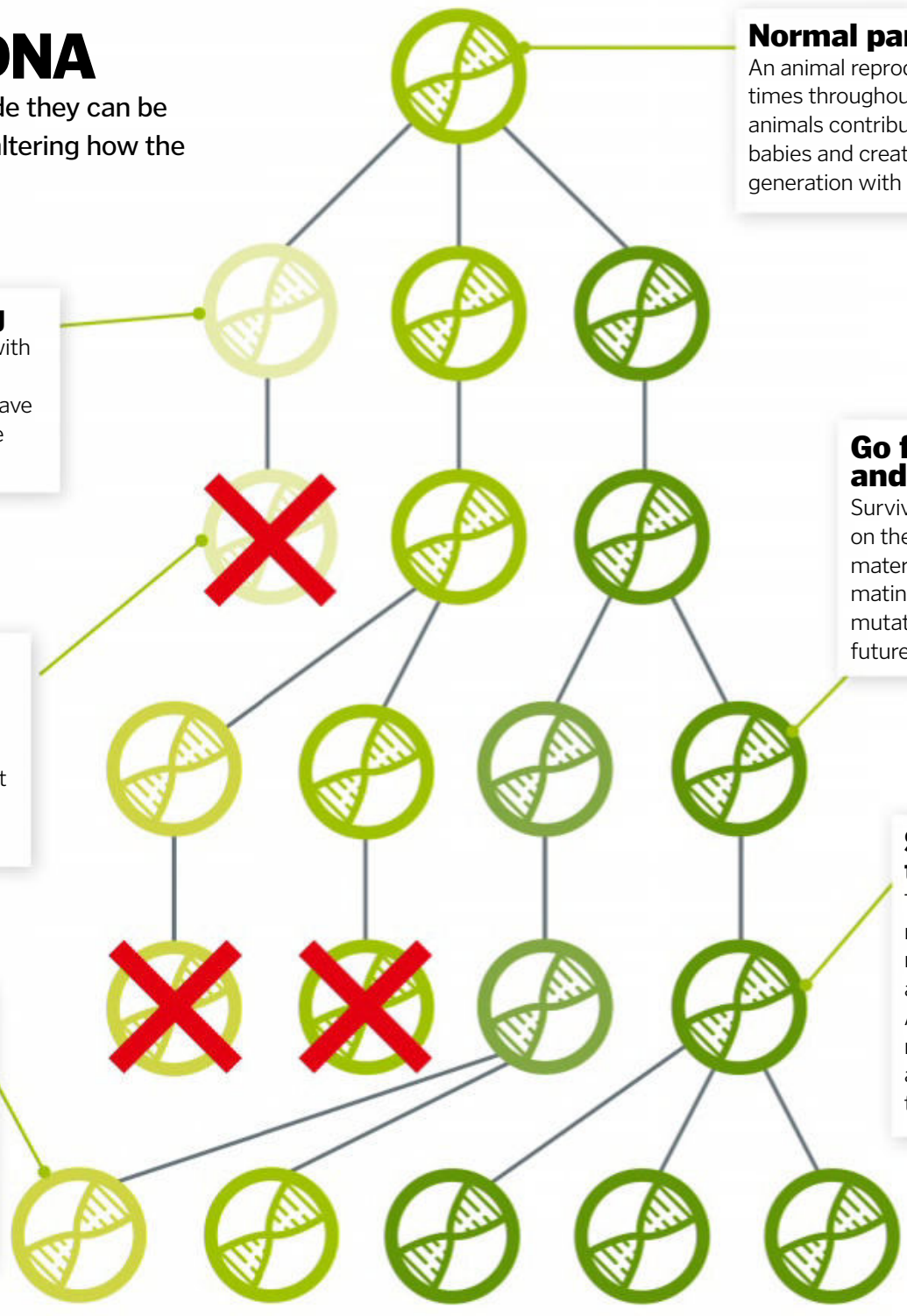
Around 50 million years ago the shores were teeming with food. Terrestrial mammals took advantage of the fish in the sea, and went through one of the most dramatic transformations in evolutionary history. Animals like the dog-like indohyus began to spend their time in the water. The first big change was in the skull. A thick wall of bone developed around the ear, making it easier to hear underwater. Soon the tail became more muscular and the limbs began to shrink. Their hair disappeared and the skull changed shape, making them more streamlined and better adapted for swimming. The nostrils of the evolving whales migrated from the tip of the snout to the top of the head. What we now recognise as a blowhole was once a nose. There are now roughly 90 species of whale, dolphin and porpoise descended from four-legged furry animals. There are still tiny vestigial bones in a whale's blubber that show its ancestors had limbs.


The tenrec of Madagascar evolved independently of the hedgehog despite strong similarities

"Advantageous genes were selected for by nature, allowing animals to change over time"

Mutant DNA

Whenever genes divide they can be subject to mutation, altering how the organism develops



Normal parents
An animal reproduces multiple times throughout its life. Two animals contribute DNA to their babies and create a new generation with different genes.

Mutant offspring
Some offspring are born with genetic mutations. These occur randomly and can have a significant impact on the animal's biology.

Go forth and multiply
Surviving animals pass on their unique genetic material through mating, spreading mutations to their future descendants.

Bad luck
Some DNA alterations made life difficult for an animal. It doesn't live long enough to breed or cannot attract a mate and its genes aren't inherited.

Survival of the fittest
The term 'fitness' refers to how many offspring an animal has. Advantageous mutations ensure an animal lives on to have babies.

Evolution in action
Different species emerge from a single ancestor in a relatively short time. Eventually the new generation is unrecognisable from its original form.

5 FACTS ABOUT HUMAN EVOLUTION

1 Out of Africa
Humans and our ancestors evolved in Africa. *Homo sapiens* migrated from their homeland 60,000 years ago and began to colonise the rest of the world.

2 Small gene pool
It's estimated that all 7.7 billion humans alive today descend from a group of around only 15,000 individuals. This has been determined mathematically from data of modern DNA.

3 The caveman inside
Neanderthal man went extinct 40,000 years ago but their genes survive today. Up to six per cent of a modern human genome can be Neanderthal.

4 Fire came first
Evidence points to humans evolving after the discovery of fire and the dawn of tool use. We grew up to be masters of the technology of the time.

5 We're still evolving
A few areas of the human genome are undergoing rapid selection. Many of these changes are associated with brain size – it turns out they're getting smaller.

What was feudalism?

In the Medieval system of power, land was exchanged for loyalty

In the Middle Ages, hard work got you nowhere. If you were born into a family of peasants, you would be expected to labour on farms but you would never own any land, and there was no social ladder to climb. That's because society in Medieval Europe was organised into different, closed groups according to status. The king was at the very top, followed by barons, knights and peasants, and each group was bound by their roles and responsibilities. Today this is known as the feudal system, but the phrase was not used at the time, and there is much debate around whether Medieval society was so straightforward.

Nevertheless the feudal system serves as an analogy for the imbalanced structure of Medieval society. The king owned all the land and ruled as he wished, but over the centuries, the absolute monarchy has been overturned. In 13th century England, for example, King John was forced to sign an agreement known as the Magna Carta, which limited his powers. Feudalism was in decline all over Europe but it remained in France until the Revolution in 1789, and lasted until 1861 in Russia when serfdom (slavery) was finally abolished and all classes were given the right to own land for the first time.

A reproduction of a Medieval manuscript shows peasants sowing fields outside a walled town

Death of feudalism

The Black Death spread throughout Europe in the 14th century, killing an estimated 50 million people. It changed society for ever. One of these changes, it's been argued, was the breakdown of the feudal system. As the numbers of peasants dwindled, there were fewer people to work the land – the main source of wealth and power for the lords, and the foundation of the feudal system.

Those who survived the deadly disease seized their chance to get richer – from lands left by the dead and by demanding higher wages in return for labour. More money meant the lower classes could afford to dress like their social superiors and a law was passed in 1363 in a bid to stop this trend. The law put restrictions on the clothes and diets of people at every level of society, but it was impossible to enforce and it's been suggested that this led to the emergence of a middle class.

A woodcut of the plague showing Death looking triumphant

Pyramids of power

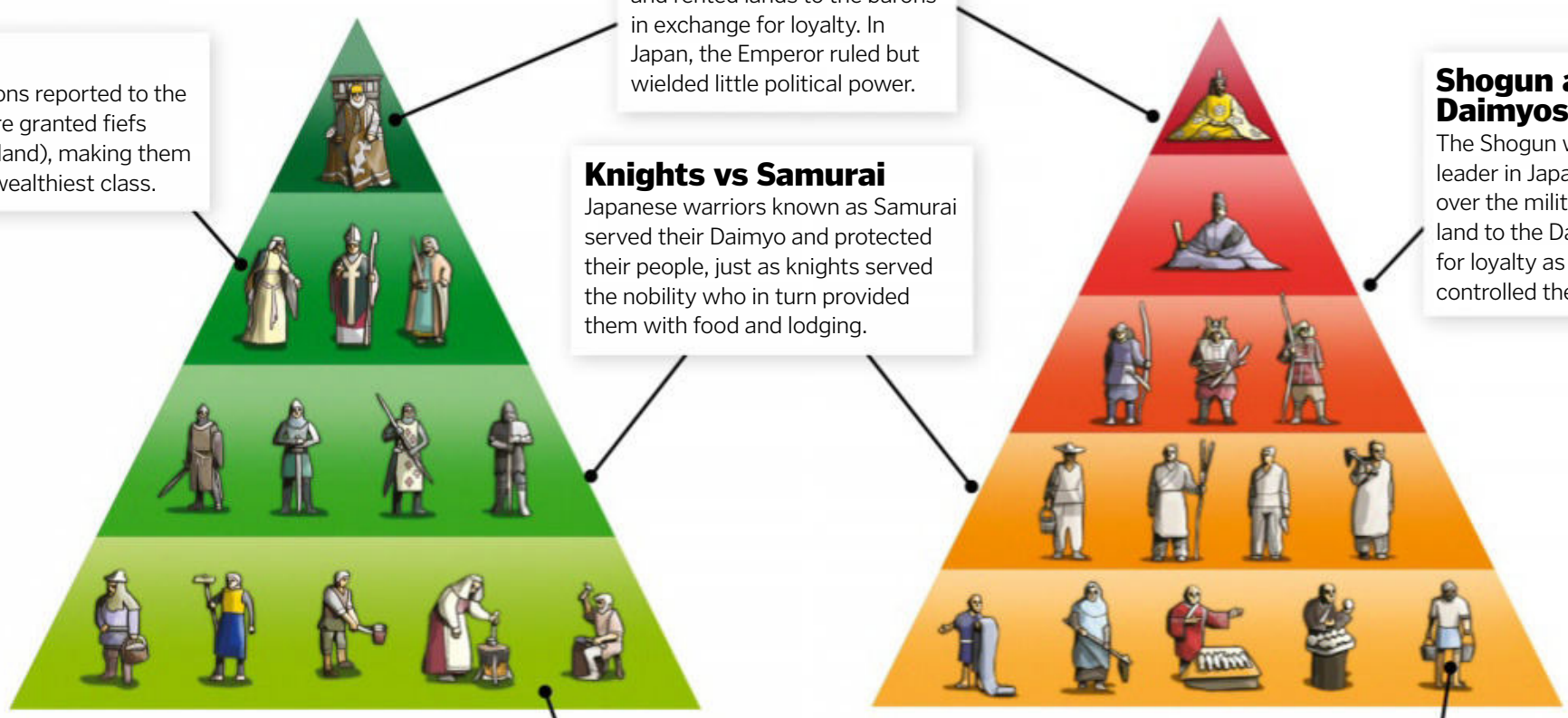
Medieval European and Japanese societies were built on similar, strict class systems

Nobility
Lords or barons reported to the king and were granted fiefs (portions of land), making them the second wealthiest class.

King vs Emperor
The king had absolute power and rented lands to the barons in exchange for loyalty. In Japan, the Emperor ruled but wielded little political power.

Knights vs Samurai
Japanese warriors known as Samurai served their Daimyo and protected their people, just as knights served the nobility who in turn provided them with food and lodging.

Shogun and Daimyos
The Shogun was the real leader in Japan, with control over the military. He granted land to the Daimyo in exchange for loyalty as the Daimyo controlled the Samurai.



EUROPE

JAPAN

Peasants
The largest class in both Europe and Japanese societies worked the land. However in Japan they were ranked higher than merchants.

Merchants
These were skilled workers who produced things like swords and clothes, but because peasants grew food, the merchants were seen as less important in Japanese society.

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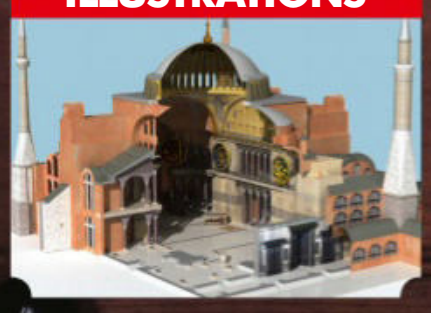
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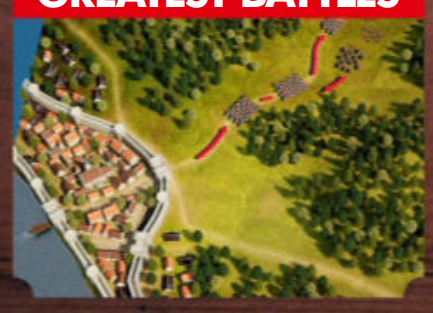
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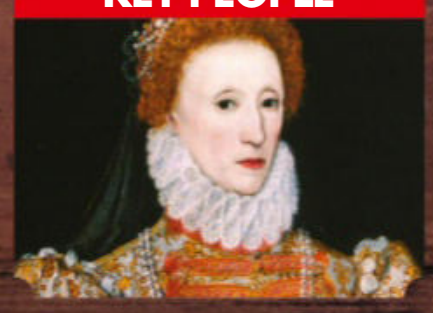
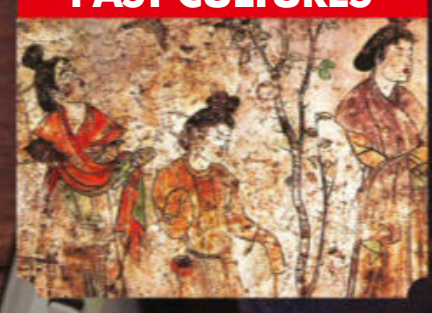

KEY PEOPLE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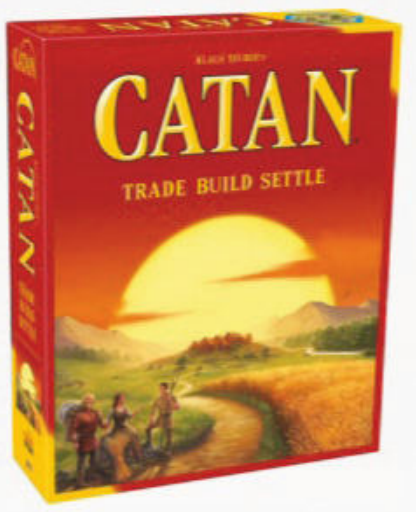
Settlers of Catan

Gather resources and populate unexplored territory to dominate the land



■ Publisher: **Asmodee** ■ Price: **£39.99** ■ Number of players: **3-4** ■ Recommended age: **10+** ■ Typical game time: **60 minutes**

Catan (as it's commonly known) distills the economics of a fledgling civilisation into a deep and accessible game. The board is built out of hexagon tiles, all but one of which is printed with one of five resources. The aim of the basic game is to be the first to earn ten victory points, which can be done mainly by building settlements and cities. However you do this, you'll need resources to build and expand.

Each player to take their turn rolls a pair of dice. When the number rolled corresponds to a number placed on a tile, any player who has built a settlement or city on one of the tile's corners will earn a unit of resource from the bank. Having gathered resources, the player may then have enough to build a road, settlement or city, or to buy a development card. Finally, the player can trade resources with others before their turn ends – and crucially, there are no rules to this.

It's surprising how much of a meta-game trade can become once you've a firm grasp of Catan: if you have a monopoly on a certain resource then you can drive as hard a bargain as you like. Securing as many units of a vital resource as possible from another player is good, but you might want to hide what resources you have. Perhaps it's more important to keep a player on-side in case a trade war or land-grab erupts and you need a decision to fall in your favour. Or it might be time to cease trading and enforce an embargo on a certain player if you suspect they're on the verge of victory. With this level of player interaction, small wonder that Catan has become so popular, spawning several board expansions and editions in multiple languages.

Expand and conquer

Catan's customisable board make even the basic game a different experience each time

Tile numbers
Assigned to tiles at the start of the game, the colour simply indicates the likelihood of a player rolling this number (red = more likely).

Roads
In order to build another settlement, you need to build roads to another corner of a tile.

Robber
If a player rolls a 7, they can move the robber token to any tile, preventing resource generation there until the robber is moved again.

Sea ports
If you build a settlement at a port, you can trade resources with the bank at a more favourable rate.

Longest road
The first player to build a road that's five or more consecutive segments long earns two victory points.

Largest army
Sometimes, development cards give you a knight. If you're the first to get three of these, you earn two victory points.

Development card
When bought with resources, these give the player a random bonus.

BRAIN DUMP

Because enquiring minds need to know...

MEET THE EXPERTS

Who's answering your questions this month?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LAURA MEARS


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How do you measure the calories in food?

Annie Warman

The calories you see on food packaging are actually kilocalories (1,000 calories) and these are defined as the amount of energy needed to raise the temperature of one kilogram of water by one degree Celsius. The calorie content of food can be measured in one of two ways. The traditional method was to place the food in a sealed container surrounded by water, known as a bomb calorimeter, and burn it to measure the resulting rise in water temperature. However, today it's usually calculated by adding up the calories provided by the food's protein, carbohydrate, fat and alcohol content. **JS**

Proteins and carbohydrates contain four calories per gram and fats have nine calories per gram

Why does someone jumping out to scare you cure hiccups?

Heike Lehmann

A sudden fright can cure these spasms of the diaphragm in two ways; by jump-starting your breathing pattern, or by activating your flight-or-flight stress response to stimulate the vagus nerve responsible for the hiccups, thus distracting it from causing the spasms. **JS**

Why aren't hovercraft more widely used?

Naomi Mohanarajah

Hovercraft are impressive machines. They're fast and versatile, able to transition from flat ground to water in an instant. Unfortunately, the popularity of hovercraft has never taken off outside of niche use. This is due to high maintenance costs, fuel inefficiency and a lack of comfort during travel, leaving alternative modes of transport more effective overall. **JH**

Why do prawns/ shrimp turn pink when they are cooked?

Jon Harman

Like other crustaceans, prawns and shrimp are encased in an exoskeleton. Placing them in boiling water loosens proteins called crustacyanin on their surface, revealing a reddish-pink exoskeleton pigment known as astaxanthin hidden underneath. **JH**

© Getty

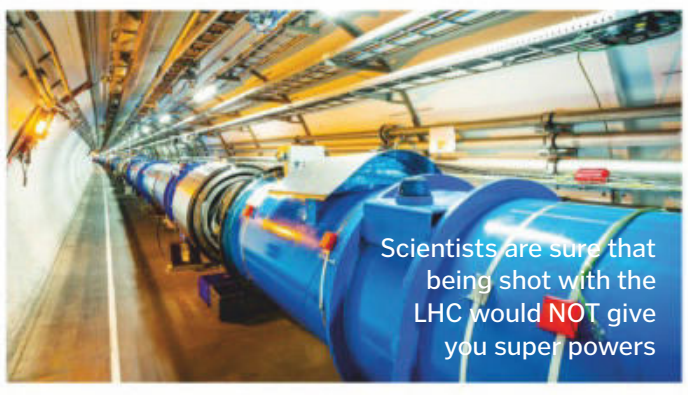
BRAIN DUMP

Cats and dogs practice running, chasing and pouncing in their dreams

Do all animals dream?

Matthew Hart

They all sleep, but they don't all dream. We can tell when a human is dreaming because their eyes start to move - that's why we call dream sleep 'REM' – it stands for rapid eye movement. Our brain activity also changes, moving from the slow waves of deep sleep to waves that look much more like they do when we are awake. Looking at the brains of other animals has revealed that mammals and birds dream too. In lab experiments, rats practiced mazes in their sleep and finches rehearsed songs. But fish and insects don't seem to dream at all. **LM**



Scientists are sure that being shot with the LHC would NOT give you super powers

What would happen if you were shot by the Large Hadron Collider?

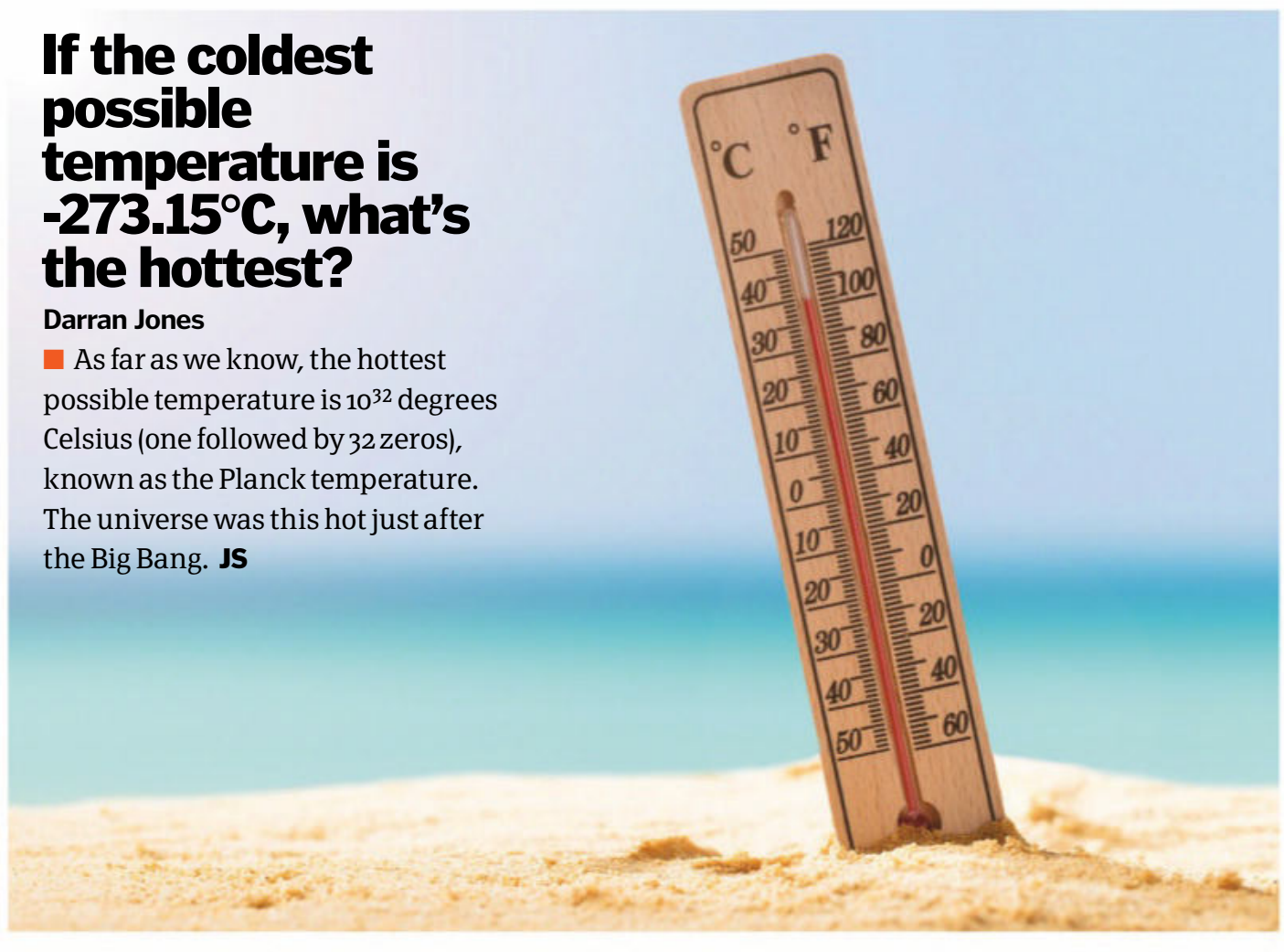
Olivia Smith

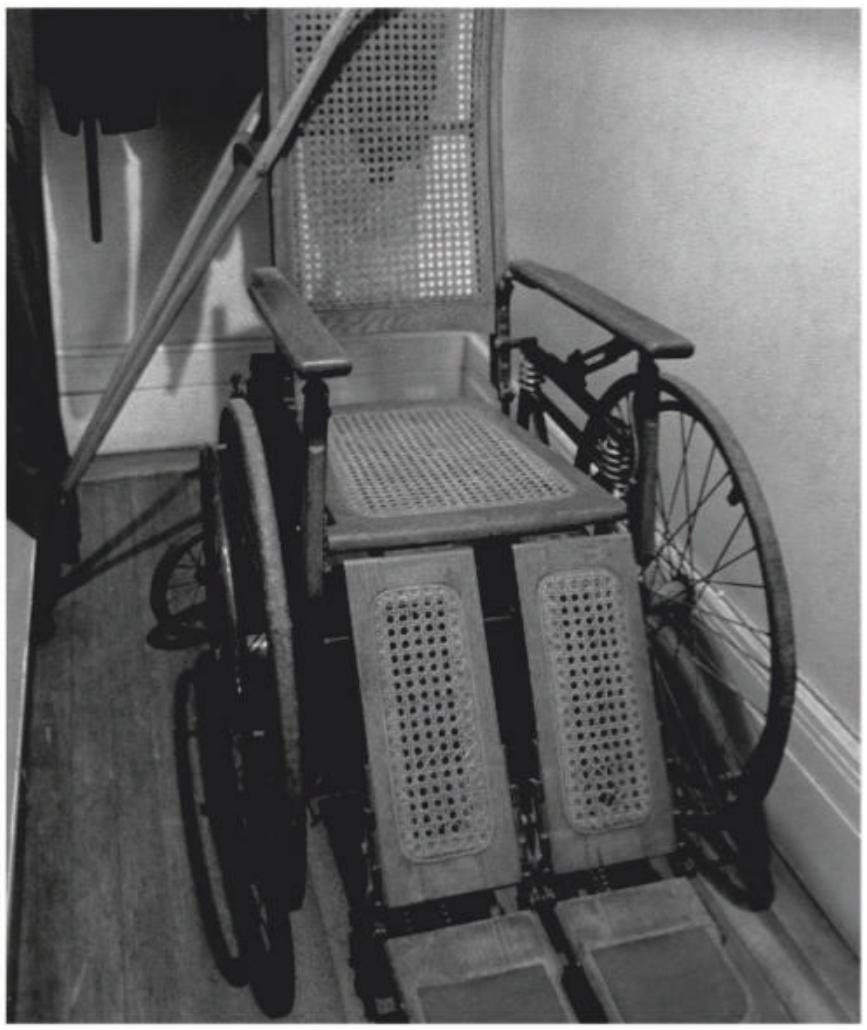
In 1978 Soviet scientist Anatoli Bugorski survived being hit in the head by the beam of a particle accelerator far smaller than the LHC. The beam missed the vital parts of his brain, but left him suffering seizures, nerve damage and a half-paralysed face. So, although scientists aren't sure exactly what would happen if you were shot by the LHC, they do know it would be bad for you, especially if it hit a vital organ. **TL**

If the coldest possible temperature is -273.15°C, what's the hottest?

Darran Jones

As far as we know, the hottest possible temperature is 10^{32} degrees Celsius (one followed by 32 zeros), known as the Planck temperature. The universe was this hot just after the Big Bang. **JS**

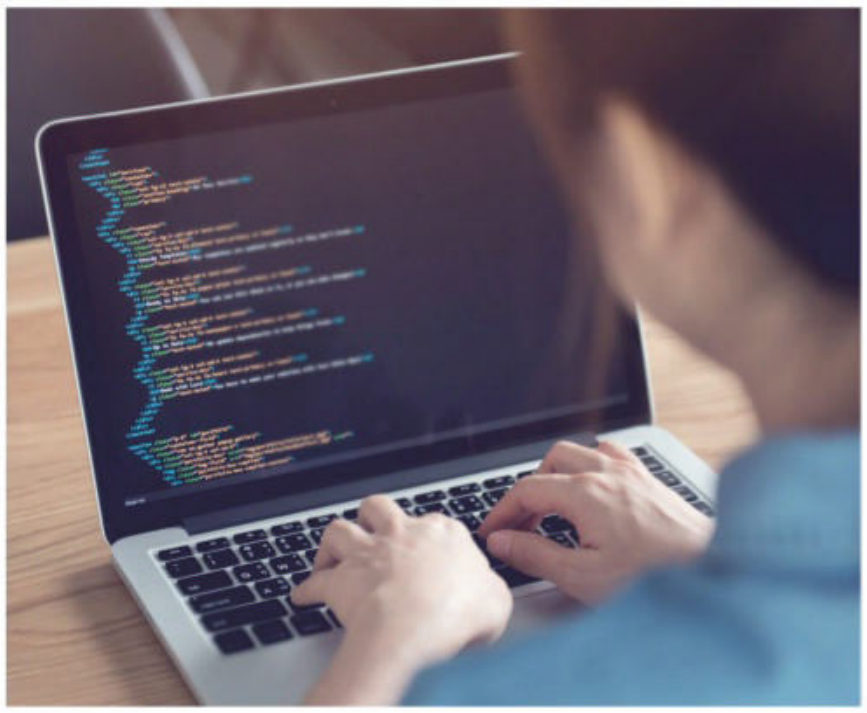




Who invented the wheelchair?

Anton Davies

No one is sure who invented the wheelchair. There are records of primitive wheeled chairs going back to at least 6th century China, that were much improved in later centuries. Today's wheelchairs owe much to American engineers Herbert Everest and Harry Jennings, who created the first modern lightweight folding wheelchair in 1933. **TL**



How does a computer read programming code?

Gareth Taylor

High-level programming languages are designed with words and concepts to make them easy for humans to use. But deep down, all a computer understands is the electrical signals that flow through its circuitry, which you can think of as ones and zeros, depending on if the voltage is high or low. To read your programming code the computer first has to use software, such as a compiler or interpreter, to convert your program from something easy for humans to understand, like IF X="10" PRINT "HELLO WORLD!", into something that the computer can understand like 01010010101010010010101 1. **TL**

The Hubble Telescope captures dark matter distorting light within a galaxy cluster

How do we know dark matter exists?

Oleg Shmetkov

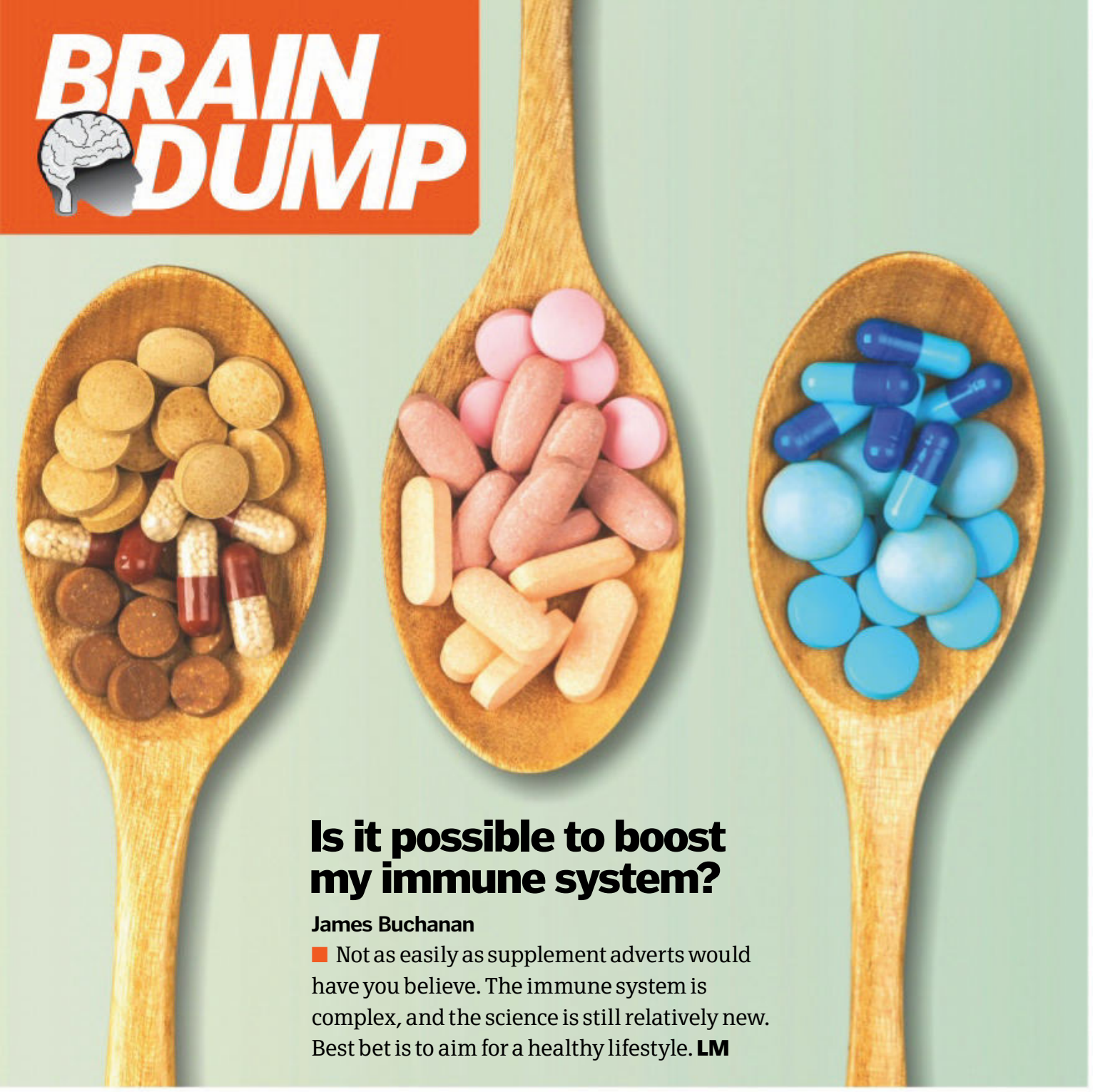
Even though dark matter can't be seen or detected with any of our scientific instruments, we know it's there because of the effect it has on other matter in the universe. For example, stars and galaxies move much faster than they should do when pulled by normal gravitational forces, so there must be something else producing the gravity to make them move in this way. The best theory is 'dark matter' made up of as-yet undiscovered particles. **JS**

Are skunks immune to the smell of their own spray?

Jessica Westbrook

Quite probably. Our noses adjust to background odours, like the scent of our laundry detergent, and it's likely that skunk noses do the same. But, even if they can't detect their own smell, they still don't like to get sprayed. Skunk spray contains irritants, which make the animals sneeze and rub their eyes. **LM**

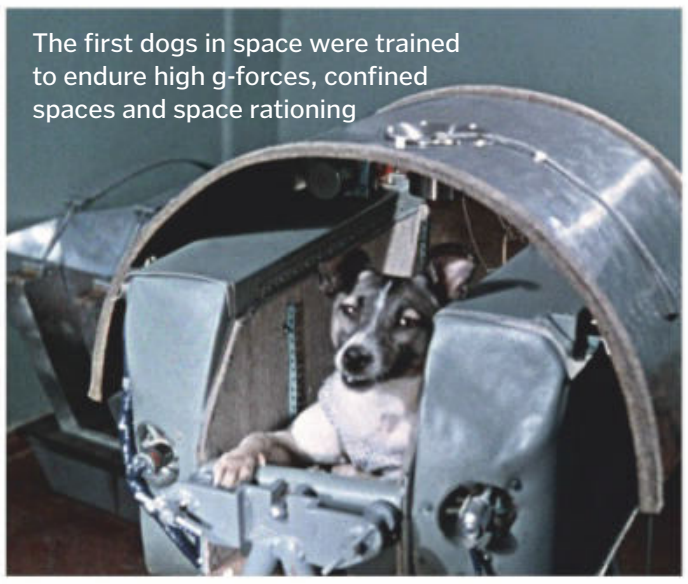
BRAIN DUMP



Is it possible to boost my immune system?

James Buchanan

Not as easily as supplement adverts would have you believe. The immune system is complex, and the science is still relatively new. Best bet is to aim for a healthy lifestyle. **LM**



The first dogs in space were trained to endure high g-forces, confined spaces and space rationing

How did they train the first dogs in space?

Aiden Jay

The first dogs in space, like their human counterparts, would be challenged with crushing g-forces during launch, subsequent weightlessness, confined spaces and unnatural rations. Female mongrels were deemed best suited for the task. Mongrels were thought of as hardier, and females didn't have to raise their leg to urinate and so could manage in a smaller vessel. They would periodically move the dogs to ever-smaller cages to naturalise them to a confined space, place them in a centrifuge to mimic high g-forces, and feed them jellified space rations. **JH**

Do probiotics do anything?

Ian Gough

Antibiotics and illness can kill good bacteria in our intestines, and there's evidence that probiotics might help us to recover. But the best tests use medical-grade probiotics, and the supplements we can buy in shops are not necessarily the same. Probiotics count as 'food', so they don't have to pass the same checks as medicines. This makes it hard to tell whether they contain enough bacteria to have the same effects that we see in trials. **LM**

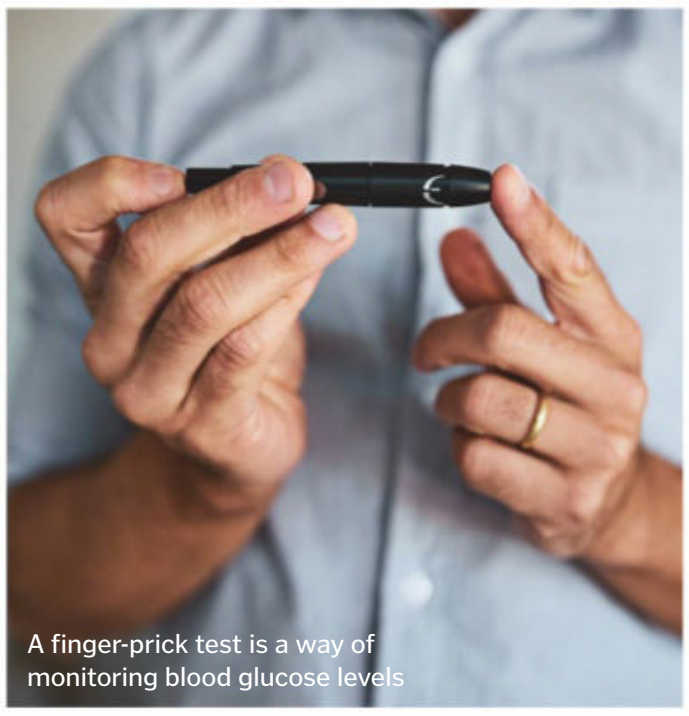
Probiotics claim to support gut health by supplying 'good bacteria'

© WIKI/Rama

What is the oldest empire?

Ollie Williams

The Akkadian Empire was established in the city of Akkad in ancient Mesopotamia – a historical region that roughly corresponds to modern-day Iraq. It was established in 2334 BCE and lasted for 180 years. **JT**



A finger-prick test is a way of monitoring blood glucose levels

Is Type 2 diabetes reversible?

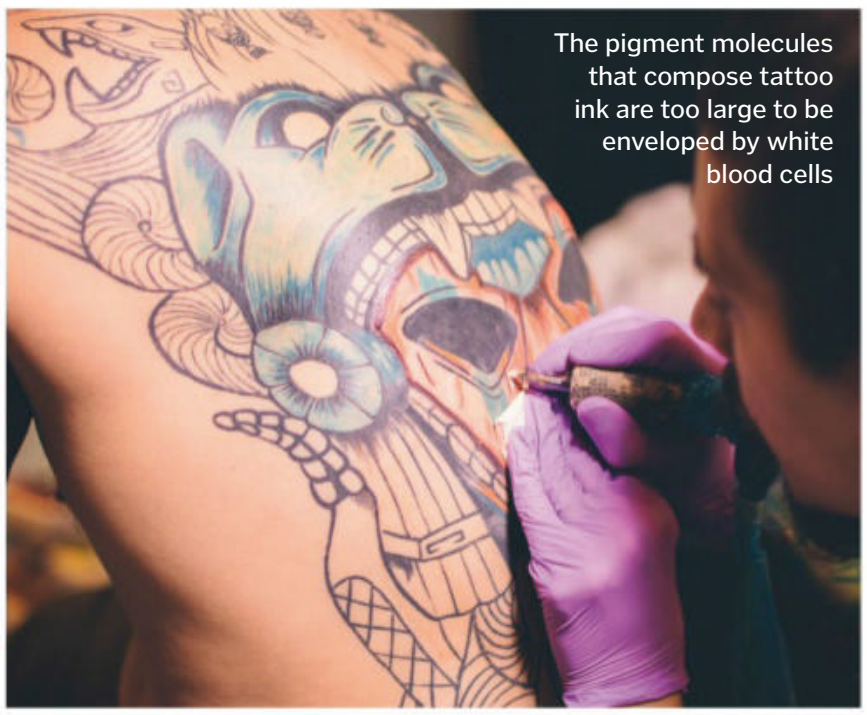
Helen Jones

Diabetes is a condition where blood glucose (sugar) levels are too high. This is usually regulated by a hormone called insulin – made by our pancreas – that allows glucose in our blood to be absorbed by our cells to give us energy. Type 1 diabetes means the body can't make any insulin, and Type 2 means the insulin produced doesn't work effectively or there's not enough. However, recent studies show that in some cases Type 2 diabetes can be reversed through weight loss. Reduced fat in the liver and pancreas allow these organs to function as normal. The term 'remission' is more accurate though, as diabetes can come back. **JT**

I read that there could be a planet hidden behind the Sun. Is that possible?

Julie Gordon

No. If there was a hidden planet there scientists would have detected its gravitational influence on other objects in space, or noticed it when NASA satellites have orbited the Sun. **TL**



The pigment molecules that compose tattoo ink are too large to be enveloped by white blood cells

How does tattoo ink stay in the skin?

Marcell Hughes

Tattoos are injected into the second layer of our skin, the dermis, which rests underneath the protective layer of the epidermis. This alone isn't enough to make tattoos permanent however, as the damage caused by the needle brings our immune response, including our foreign body-eating white blood cells, to the site. Unfortunately for the white blood cells, the injected pigment molecules are too large to be consumed, meaning the ink can hang around indefinitely. The permanency of tattoos is a double-edged sword, as they can be difficult to remove. The most effective current approach is laser treatment, which involves targeting light on a single colour. This breaks the pigment molecules into smaller pieces that can subsequently be feasted on by white blood cells. **JH**

Want answers?

Send your questions to...

How It Works magazine
@HowItWorksmag
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Around one in ten of us regularly experience 'sun sneezes'

Why does bright light make me sneeze?

Jacob Wall

This is known as the photic sneeze reflex, or ACHOO (autosomal dominant compulsive helio-ophthalmic outbursts of sneezing) syndrome. 'Autosomal dominant' means you only need to inherit the gene from one of your parents to have the trait. However, we still don't know exactly how light entering the eyes can lead to a sneeze. **JT**

BOOK REVIEWS

The latest releases for curious minds

Buzz

Who knew bees were so interesting?

- Author: **Thor Hanson**
- Publisher: **Icon Books / Basic Books**
- Price: **£9.99 / $17.99**
- Release: **Out now (UK) / 3 September (US)**

You know something is a big deal when it's a plot point in *Doctor Who*. We've known about the declining number of bees for years now, and it's more than just science fiction. Bee science has become a mainstream interest recently. Unlike many recent books, though, Thor Hanson's *Buzz* doesn't aim to capitalise on this popularity by talking about the dwindling number of honeybees. In fact, Hanson dedicates much more of his time to wild bees, talking about how they evolved and what challenges they face in the modern world.

Like many of the best modern science books, Hanson makes the journey personal. He centres each chapter around a specific place, experience, or bee, and tells stories of his research (and his life) to bring readers more deeply into the story of the bee. It's genuinely effective, and in many cases you'd be forgiven for forgetting that you're reading a science book at all. When Hanson describes how "the meadow stretched seductively across a small mounted basin", it's easy to see why his readable prose kept us turning pages.

Of course, among this entertaining, individual story is plenty of interesting scientific insight. We find out how bees evolved from wasps, explore pollination and the relationship between bees and flowers, and admire, in intimate and sometimes squirm-inducing detail, the physical makeup of bees. Along the way we pick up some astonishing facts – did you know, for example, that a bee's antennae are so sensitive that they can track the drifting fragrance of a flower to its source from well over a kilometre away? Or that bees can see ultraviolet light – which means they see something quite different to us when they look at a flower?

It's not all wonder, though. Hanson also tells us the dreaded truths we knew were coming when we opened *Buzz*. The increased global trading of fruit, vegetables and even bees, and the increase in chemicals in nature are all contributing to the reduction in bee numbers. Thankfully, there's a positive note to end on – a success story of farmers who understand the importance of these tiny pollinators and have worked to create a sustainable, healthy business – for themselves, and the bees. It won't appeal to everyone, but if you have even a passing interesting in natural history there's plenty to love here – make a bee-line for it.

★★★★★

"Along the way we pick up some astonishing facts"

Six Impossible Things: The 'Quanta Of Solace' and the Mysteries of the Subatomic World

Small mysteries

- Author: **John Gribbin**
- Publisher: **Icon Books / MIT Press**
- Price: **£9.99 / $19.95**
- Release: **Out now (UK) / 8 October (US)**

Perhaps unjustly, the field of quantum physics has garnered a reputation as a somewhat impenetrable and intimidating subject matter. Admittedly, much of what goes on in the subatomic world is beyond our current comprehension, but isn't discovering what lies beneath part of the fun?

With John Gribbin at the helm (previous writings include books on Schrodinger's Cat and the true age of the universe), we have someone best placed to delve into the inner workings of the micro world. Divided into six chapters, each is dedicated to the 'big six' interpretations of how it all works.

Conventional rules of common sense don't always seem to apply to quantum physics, making each chapter surprisingly divergent in its approach (the inclusion of a foreword quoting *Alice's Adventures in Wonderland*, and the name of one of the chapters being 'The Incoherent Decoherence Interpretation' are a sign of things to come).

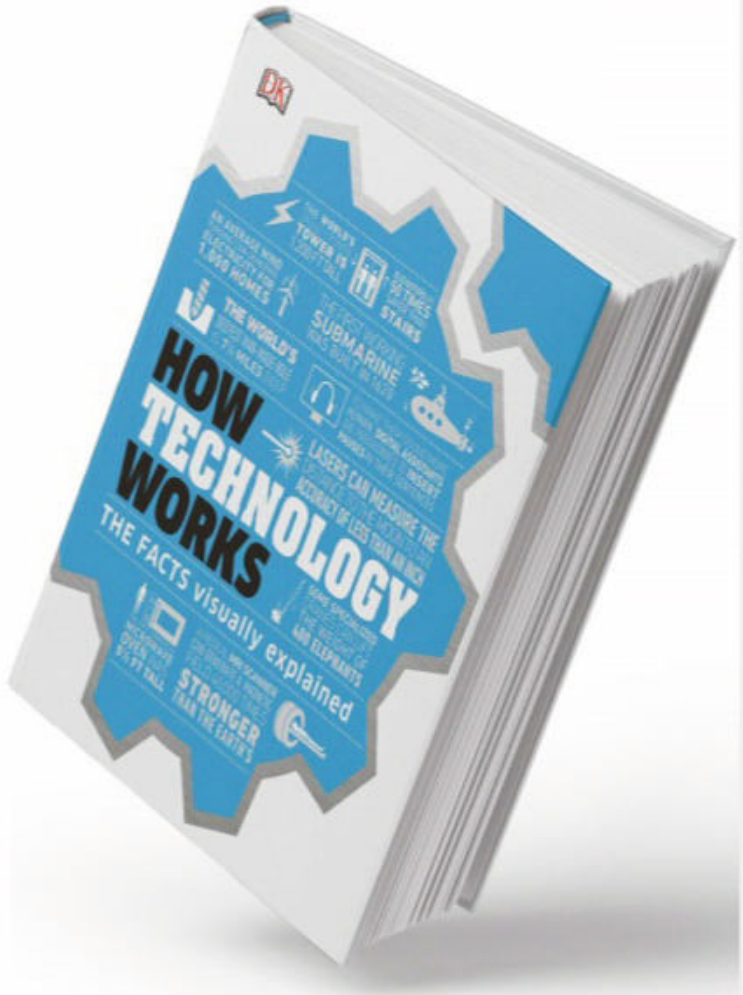
Inevitably, things will appear to get convoluted very quickly if you don't have at least a working knowledge of the subject matter, which in all honesty is pretty unavoidable. But those who stick with it will find plentiful matter for thought, and it's hard not admire Gribbin's bold approach to laying the subject bare.

★★★★☆

How Technology Works

Your guide to modern life

- Author: **DK**
- Publisher: **DK**
- Price: **£16.99 / $22**
- Release: **Out now**



A subject matter very much close to after our own hearts here at **How It Works**, *How Technology Works* talks us through the inner workings of all sorts of fixtures of modern-day life, from structures like oil refineries and power lines, to vehicles like bicycles and cars, and more recent fixtures such as drones and space probes, as well as the technologies that could ensure our future survival.

DK has always been adept at breaking down subject matter into easily digestible pieces via their well-spun annotated diagrams, and the same is the case here, with their trademark presentation being among the best we've seen, even by their high standards.

Also included is a dizzying array of trivia – the cover is packed with examples to give you a sign of what to expect, but in truth this is just scratching the uppermost surface of what is included within its pages. That the subject matter is also somehow ageless, appealing to pretty much every demographic, is another notable achievement.

There are few homes that don't have a DK book lurking around somewhere, and it's books like these that hammer home just why this is the case. We can't remember the last time we enjoyed something like this so much, and we recommend you join in the fun.

★★★★★

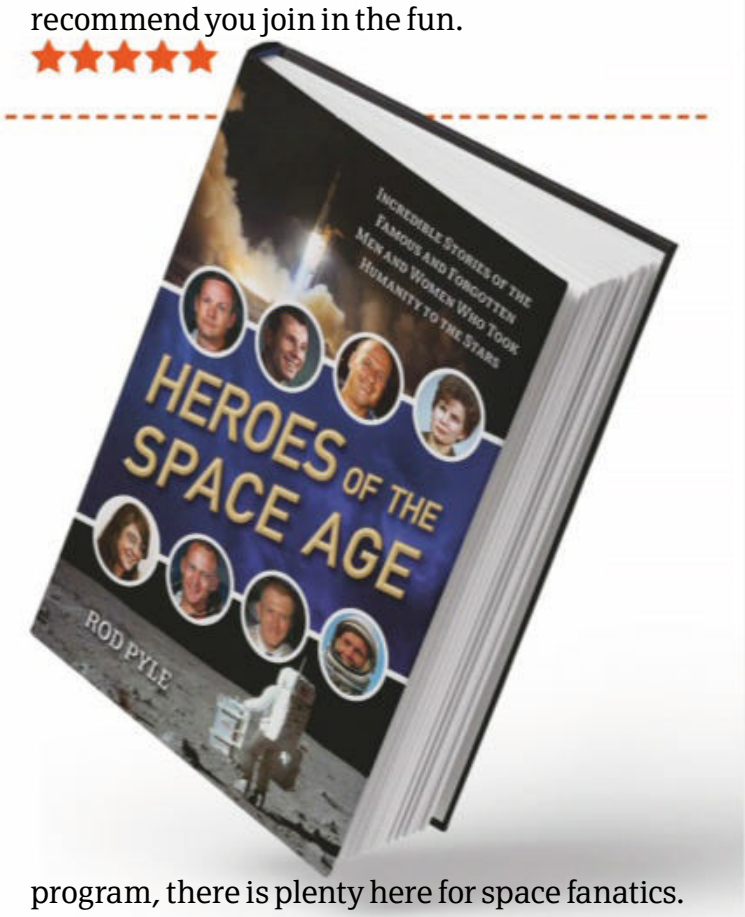
Heroes of the Space Age

Planeteering pioneers

- Author: **Rod Pyle**
- Publisher: **Prometheus Books**
- Price: **£14.99 / $18**
- Release: **20 May (UK) / Out now (US)**

When we think of humankind's impact on space, certain figures pop to mind. Neil Armstrong and Buzz Aldrin will forever be associated with the Moon, and the Soviet cosmonaut Yuri Gagarin has cemented his place in the history books. They are all covered here, but it's perhaps the lesser-known figures included within these pages who will be of the most interest.

From Charles 'Pete' Conrad, the third man to walk on the Moon, through Valentina Tereshkova, the first woman to have flown in space, to Margaret Hamilton, who helmed the onboard flight software for the Apollo space program, there is plenty here for space fanatics. We can't confirm exactly how much of the information here is new or in any way revelatory, but it's all efficiently presented.



Being more a description of events rather than anything analytical, it's hard to separate this from a lot of what's already on sale, but this is a decent effort nonetheless.

★★★☆☆

Gardening with Emma

Outdoor life explored

- Author: **Emma Biggs, Steven Biggs**
- Publisher: **Storey Publishing**
- Price: **£14.99 / $18.95**
- Release: **Out now**

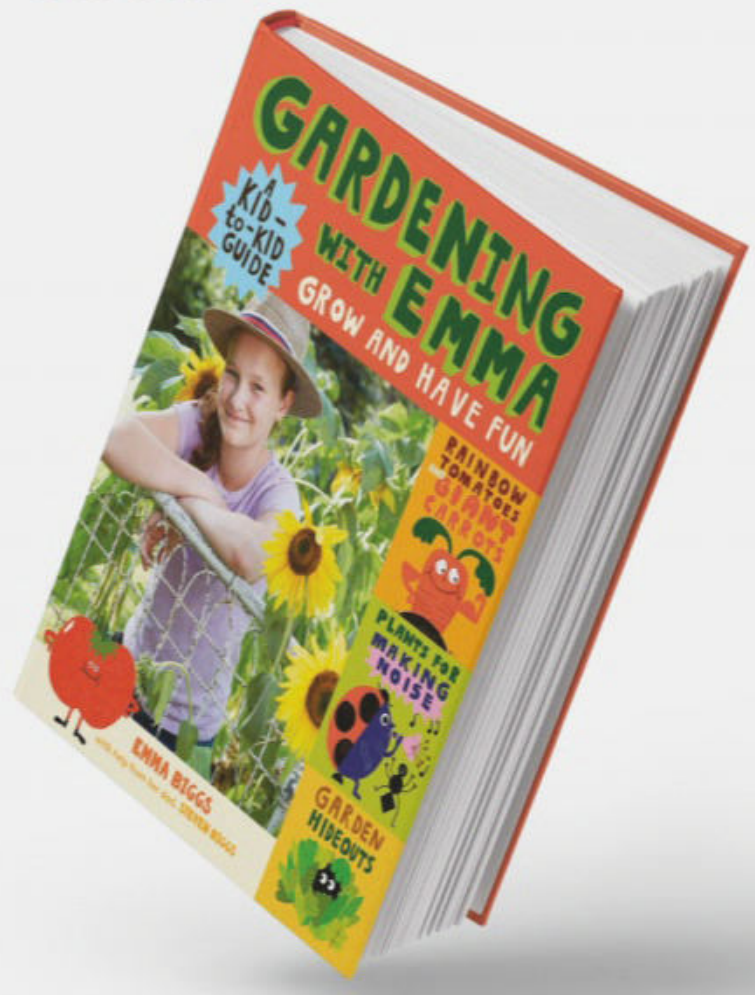
Question: how do you solve the problem of books purportedly written with kids in mind sounding a tad condescending? Answer: have it written by an actual child.

Admittedly, Emma Biggs has had a bit of help from her father Steven, but, still, it's a novel approach. Pictures of Emma at work in the garden sprinkled throughout the book keep things personal, as do the various anecdotes that accompany all of the instructional guides.

Everything included will be relevant to younger readers – such as when to water plants, how much sunlight to give them, and a guide to creepy crawlies – as well as things you might not necessarily expect to be included, such as what plants are safe to forage for. In this regard, it's probably more notable for surprise chapters like this one.

We'll own up to being pleasantly surprised: rather than a mere gimmick, this is a genuinely insightful guide to gardening for younger readers.

★★★★★



BRAIN GYM

GIVE YOUR BRAIN A PUZZLE WORKOUT

Wordsearch

X	P	S	V	M	O	O	N	K	I	L	E	R	U	T
F	I	Q	A	X	W	A	T	C	H	N	V	E	C	R
I	L	R	D	Q	L	P	B	O	Y	B	O	M	E	T
T	O	R	N	A	D	O	E	B	L	T	L	E	N	U
H	T	O	U	T	N	H	T	G	A	V	U	L	T	P
E	P	E	F	Q	N	X	E	W	D	Q	T	J	R	I
A	S	T	E	A	M	E	L	M	U	L	I	O	I	P
R	A	E	T	Y	I	N	G	V	E	X	O	E	F	T
I	R	E	D	I	Y	U	E	C	F	M	N	N	U	Y
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G	A	I	E	Y	O	L	S	D	E	B	M	X	E	T
V	G	C	E	R	Y	E	E	O	N	E	Y	Q	W	U
E	I	N	Y	C	B	A	E	O	A	M	O	R	U	P
R	A	E	W	T	Y	R	S	L	B	Y	O	P	G	A
S	U	B	M	E	R	S	I	B	L	E	U	B	R	M

FIND THE FOLLOWING WORDS...

PILOT
CENTRIFUGE
SUBMERSIBLE
TORNADO
BLOOD
HEARING
NUCLEAR
CYBORG
GIN
MOON
WATCH
BETELGEUSE
STEAM
EVOLUTION
FEUDAL

Quickfire questions

Q1 What does the 'g' in g-force stand for?
- Gain
- Gram
- Gravity
- Gastronomy

Q2 Which animal has the keenest sense of smell?
- Dog
- Elephant
- Rat
- Chimpanzee

Q3 What is Chang'e 5?
- A terrestrial satellite
- A lunar mission
- A Martian probe
- A rocket

Q4 How far from Earth is Betelgeuse?
- 63.2 billion kilometres
- 61 light years
- 600 billion light years
- 640 light years

Spot the difference

See if you can find all six changes we've made to the image on the right

Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9

EASY

9			7		1	5	3	4
8		4	3	6		9		1
3	5					8	7	6
7	4	6	2	5	9	3	1	8
			6	3	7			
		3	1	4			6	2
1		7			2	6	4	
4		9	8		6		5	7
	2	5			3	1	8	

DIFFICULT

	1			9				
2	4				3		7	
								6
	5	2		8		9		
		6	1					5
3	7				9			2
		4	3		6			
		3			1			
	9	7				4		

What is it?

Hint: This is a type of wood used to seal certain glass bottles.

A .....

© Getty

Spot the difference

Check your answers

Find the solutions to last issue's puzzle pages

Quickfire questions

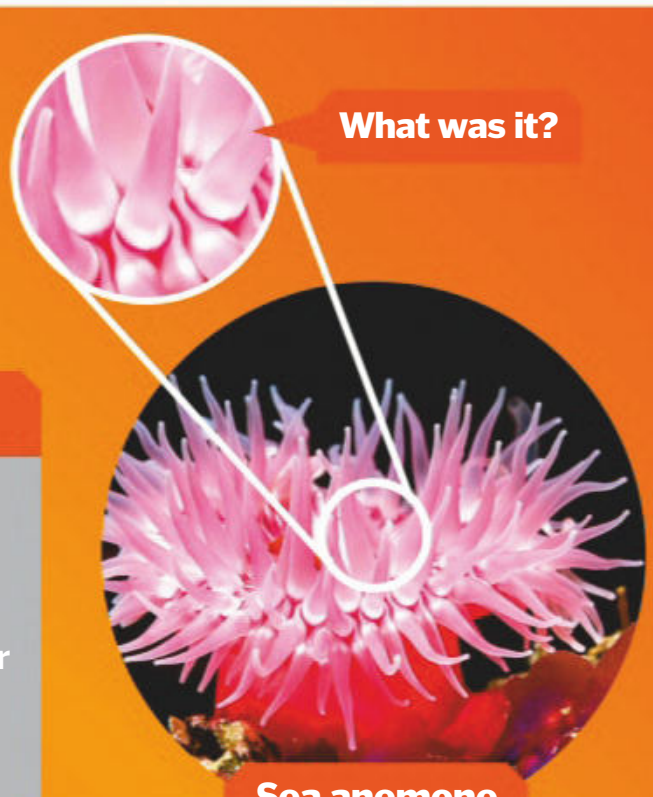
Q1 Phalanges

Q2 Antarctic

Q3 1,000 kilometres per hour

Q4 Nitrogen

What was it?



Sea anemone

WIN! OUTDOOR GOODIES

WORTH OVER £150

VARTA Outdoor Sports F30 torch

Powertraveller Solar Adventurer

Haynes' Outdoor Survival: A Step-By-Step Guide to Practical Bush Craft and Survival Outdoors by Dave Pearce

VARTA Slim Power Bank 6000

For your chance to win, answer the following question:

What does RAF stand for?

a) **Royal Air Fighters** b) **Royal Air Force** c) **Royal Aircraft Fleet**

Send your entries by email to **howitworks@futurenet.com** with the subject 'Competition 125', or write to us at:

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DON'T DO IT ALONE
IF YOU'RE UNDER 18, MAKE SURE YOU HAVE AN ADULT WITH YOU

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Send your ideas to...
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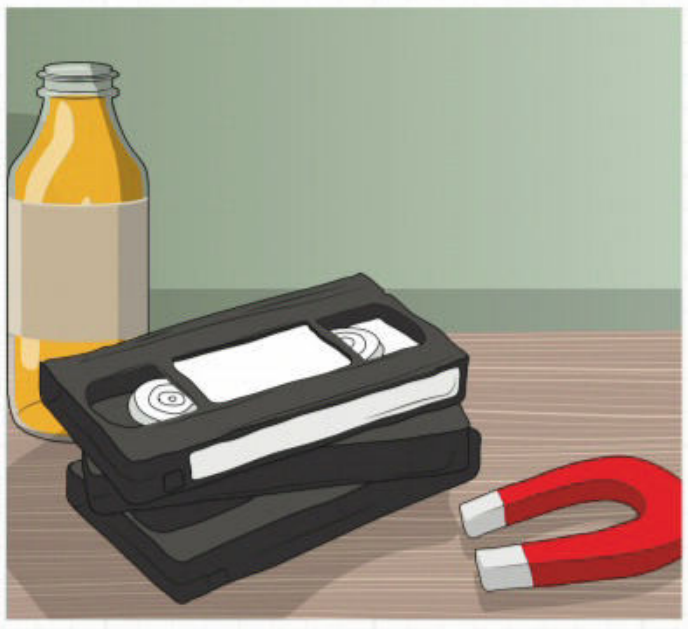
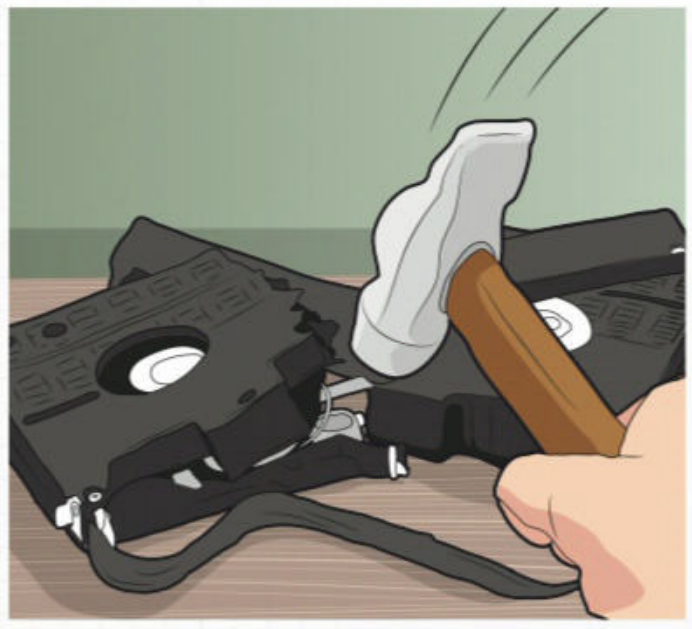
Create a ferrofluid

Make a liquid that reacts to magnets, without breaking the bank



1 Gather your materials

For this experiment you'll need some magnetic material. You can get it from the black plastic inside an old cassette or VHS tape, so find as many as you can. You'll also need acetone to remove the magnetic material.



2 Prepare the tapes

Break open the cassettes and VHSes to get to the black tapes inside. Unravel them to get the largest possible surface area. These tapes use an oxide of iron, which is attached to the plastic with a binding agent.

3 Soak them

Find a large plastic bowl and fill it with acetone. Place the tapes into the acetone, cover the bowl, and wait a few hours. The acetone breaks down the binding agent in the tapes and the ferric oxide will fall off.

4 Gather it up

Get a strong magnet (like one from an old speaker). Put it in a plastic bag and use it to gather the ferric oxide in the bowl. The bag makes it easier to get the ferric oxide off the magnet.

5 Mix it up

Mix the ferric oxide with cooking oil. For 1ml of ferric oxide you need 1/3ml cooking oil. If it's too viscous when you mix it, add a drop of water and some detergent until you have a thick liquid.

6 Test it out

Move your magnet under the ferrofluid, and you should see it spike up as the metal in the fluid reacts to the magnetic field. Try different-sized magnets to see how the reaction changes.

SUMMARY...

Outside of a liquid, the solid pieces of ferric oxide would bunch up next to the magnet at the bottom of the container. However, because of the increased surface area in the liquid, this can't happen. The particles are evenly distributed, and when a magnetic field is introduced, the particles realign to the magnetic field lines.

Had a go? Let us know! If you've tried out any of our experiments – or conducted some of your own – let us know! Share your photos or videos with us on social media.

NEXT ISSUE
Make instant ice

INBOX
Speak your mind...

Get in touch
If you have any questions or comments for us, send them to:

How It Works magazine @HowItWorksmag howitworks@futurenet.com

It not just the size of our brains that makes humans such smarty pants

Letter of the Month

Superior smarts

Hi **HIW**,

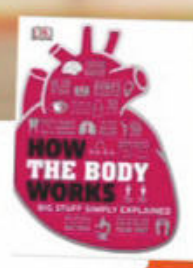
Are humans the smartest creature on the earth?

Elise Bhotia

Thanks for your question, Elise. Although it might not always seem to be the case, scientifically speaking, yes humans are indeed the most intelligent species on our planet. The explanation as to why, however, is a combination of cognitive prowess and comparative mass.

Our big brains have evolved in such a way that allows us to have heightened cognitive abilities when compared to our animal neighbours. However, it's a common misconception that bigger is better when it comes to brains. For example, by far the largest brain on Earth sits in the head of the sperm whale and can weigh up to nine kilograms. The human brain, on the other hand, only weighs around 1.4 kilograms, so why aren't whales cleverer than us? The answer is believed to be somewhat related to the ratio between brain and body size. By using a measuring formula called the encephalization quotient (EQ), brain size can be predicted by an animal's body size. Although a sperm whale's brain is bigger than ours, when using the EQ it's brain is particularly small compared to its body size. Humans, on the other hand, have a brain that is around seven to eight times larger than a mammal of the same body size.

This comparative method, however, isn't without exception and not an exact way to explain intelligence. It's what makes up the brain that results in greater smarts. Mammal species have a part of the brain known as the cerebral cortex, responsible for higher cognitive functions such as memory and communication, but ultimately defines a species' intelligence. This cortex is absent in fish, birds and reptiles and thus, reduces their intellectual capabilities. In humans not only do we have this cortex but it's bigger when compared to many other mammals.



WIN! HOW THE BODY WORKS

With clear, easy-to-understand graphics and packed with fascinating facts, this visual guide demystifies the complex processes that keep us alive.

Microscope mystery

Hi **HIW**,

Who created the microscope and how does it make everything small look giant?

Thanks, Isabel Daniells

We still aren't sure. The first patent application came from Dutch inventor Hans Lippershey in 1608. His design required looking through a pair of concave lens to produce an image three times larger than previously seen. However, optical makers Jacob Metius and Zacharias Janssen also laid claim to the invention. What we would now call a light compound or optical microscope works by passing light through a sample that passes through a series of magnifying lenses, delivering an enlarged image. Currently, there are several evolutions of the telescope since its invention.

An optical microscope uses at least two concave lens to enlarge an image

Taste sensation

Hi **HIW**,

I was in a restaurant the other day enjoying a tasty meal when the thought crossed my mind, how am I tasting this food? I'm hoping you can enlighten me as to how our tongues detect flavour.

Kim Warren

Our tongues are able to detect five basic tastes: sour, bitter, salty, sweet and umami (savoury). This is thanks to the tiny taste buds known as papillae that cover the surface of the tongue. These act as chemical receptors for food, whereby receptor cells send signals to the brain to alert it to different tastes. However, it's the combination of this detection and the smell that let us identify flavours.

Chapped lips

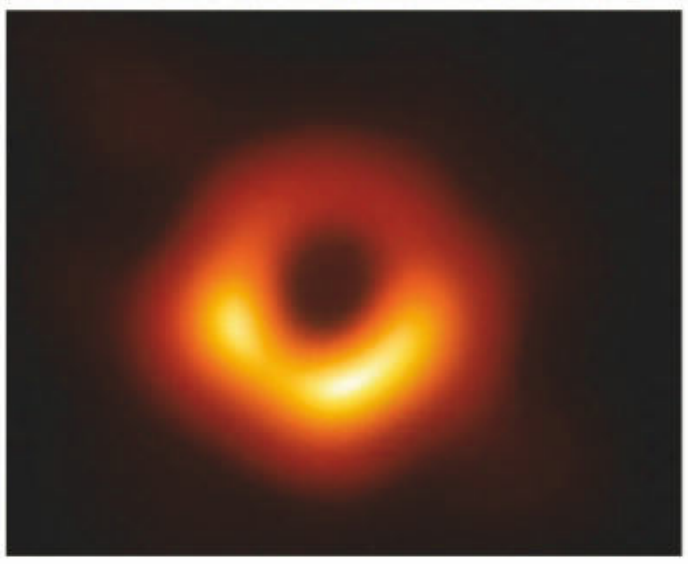
Hi **HIW**,

Why is it that during the cold winter season my lips become chapped and split?

Greg Brannon

Good question. Unfortunately, cracked lips aren't just something that can occur during winter. The reason our lips chap is the result of moisture evaporating from the skin. In turn, the skin becomes tightened and split in a similar way to the skin of fruit when it's left out for too long and becomes dehydrated. This is only made worse by licking our lips, which removes vital grease that coats the lips and holds in moisture. By using a lip balm, that grease is replaced and lips can be rehydrated.

Licking your lips when they are chapped will only make matters worse



© EHT Collaboration

Seeing the invisible

Hi **HIW**,

I've been wondering how will we get a photo of a black hole?! Because there is no light inside a black hole. It's just a massive vacuum. Thanks for reading this letter. And have an amazing day.

Olerando

It does seem like an odd concept to take an image of something that can't be seen alone. Technically, as you said there is no light able to pass a black hole, so what the image shows is the radiation and debris from material that is falling into the black hole's gravitational pull.

www.howitworksdaily.com

What's happening on... social media?

This month, we asked you if you could fly a fighter jet ~~where in the world would you~~ go and why?

@Twinklestar192

"I would love to fly all around it in various directions just to see all the various natural landscapes from above"

@petmad53

"Would really like to go to Egypt and see the pyramids"

@snozzlefloss

"I would fly over Canada in the Fall to see the stunning colours that nature gives us"

@helenharding83

"I'd love to fly over Australia to take in the cities and jungles with no worry of the creepy crawlies"

@vincenta21

"Grand Canyon Arizona would be so exciting to see,I find it fascinating!"

fighter jets from different eras fly in formation

HOW IT WORKS

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FAST FACTS

Amazing trivia to blow your mind

CYBORG MOHSEN MINAEI HAS A CHIP IN HIS CHEST THAT VIBRATES WHEN HE FACES NORTH

5 MINUTES

THE INITIAL LETHAL EXPOSURE TIME TO CHERNOBYL'S RADIOACTIVE 'ELEPHANT'S FOOT'

500 MILLION YEARS

NAUTILUS, A MARINE MOLLUSC, HAS BEEN AROUND SINCE LONG BEFORE THE DINOSAURS

125-TON

THE WEIGHT OF THE BLOW DELIVERED BY THE BETHLEHEM STEAM HAMMER

46.2 GS

THE HIGHEST G-FORCE A HUMAN HAS SURVIVED (JOHN STAPP, 1954)

5 MILLION

APPROXIMATE NUMBER OF RED BLOOD CELLS IN A SINGLE DROP OF BLOOD

HISTORIAN SUSAN REYNOLDS SUCCESSFULLY ARGUED IN 1994 THAT THE 'FEUDAL SYSTEM' NEVER EXISTED

3.2 KILOMETRES

THE DISTANCE AT WHICH AN EAGLE CAN FOCUS ON A RABBIT

YOUR PALM AND THE UNDERSIDE OF YOUR FINGERS CANNOT TAN

$2.3 BILLION

THE COST OF THE MIGALOO M7 PRIVATE SUBMERSIBLE YACHT

1973 THE YEAR THE FIRST MOBILE TELEPHONE CALL WAS MADE

0

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